Microlithographic Mask Development (MMD)

MMD Contract Summary Report

CDRL D005

20 March 1996

Contract Number N00019-94-C-0035

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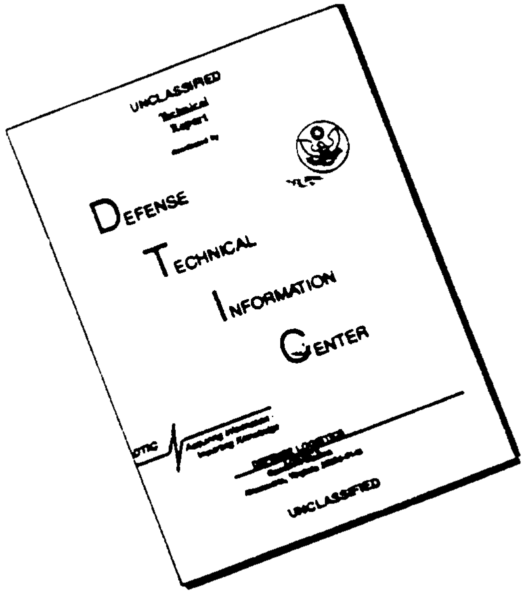

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CDRL D005

20 March 1996

ENCLOSURE NO: 96-MMD-LFSC-00020

Prepared for:

Naval Air Systems Command
1421 Jefferson Davis Highway
Arlington, Va. 22243-5120

Contract Number N00019-94-C-0035
Loral Federal Systems-Manassas

Loral Federal Systems Company, Manassas, Virginia

Certification of Technical Data Conformity

The Contractor, Loral Federal Systems Company, hereby certifies that to the best of its knowledge and belief, the technical data delivered herewith under Contract Number N00019-94-C-0035 is complete, accurate, and complies with all requirements of the contract.

March 19, 1996

Date

SG Schnur

S.G. Schnur, Program Manager

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1.0 Introduction

This document, Contract Summary Report, is submitted in accordance with CDRL D005 under contract N00019-94-C-0035 and covers the period from 23 December 1993 through 31 January 1996.

Monthly, and later quarterly, Contractor Progress, Status, Management Reports have been submitted in accordance with CDRL D004. These reports have provided significant technical detail and insight into accomplishments and problems encountered during the contract period. This report does not address the same information to the level of detail reported monthly or quarterly but does review highlights, accomplishments and technology issues.

Program Summary

The contract period began with the establishment of manufacturing capability for prototype x-ray mask builds by targeting both technical and manufacturing issues. By July of 1994, technical focus for x-ray mask build was redefined, falling in line with optical lithography strategy. The Semiconductor Industry Association (SIA) Lithography Roadmap recommended changing MMD emphasis to 0.25μm and 0.18μm generations rather than the original 0.35μm and 0.25μm. Established goals were measured by following the progress of three product types: EXPO, NIGHTHAWK and TALON. The image size target for prototype masks started at 0.25μm for EXPO and progressed to 0.18μm for NIGHTHAWK. TALON, a 0.25μm critical dimension (CD) test mask, provides a large process window for MMD learning. Engineering teams were charged with solving some major problems during the contract period:

- Both EL-3+ 50kV systems were converted to 75kV.
- The new EL-4 P0 system was moved from East Fishkill and installed in Burlington, where it was debugged and given a conditional qualification.
- Throughput analysis was completed and pinch-point tools were identified with plans to relieve their workload.
- The positive e-beam resist was changed from TNS to PMMA.
- Membrane thickness was changed from 2.5μm to 5.0μm.
- The NIST-standard substrate format was implemented, requiring new tooling and upgrades to many of the existing tools.
- Production baselines were established for performance measurement. The primary metrics were image size, image placement and defects.

2.0 Validation Study (Task 1)

Task Objective: ***Develop a pilot line validation study for the production of masks with test and/or circuit patterns that use 0.25μm and 0.18μm design rules.***

2.1 Validation Plan Updates: CDRL C001

The Validation Plan contains the metrological plans, validation procedures, production goals, and reporting for the contract period. It includes plans for both x-ray and phase shift mask technologies, but its primary focus is on x-ray mask technology since that is where the effort has been concentrated. As required by the contract, this document was updated annually and prior to the design reviews. In some cases, one update covered both the annual and design review requirements.

Figure 1 shows the x-ray validation schedule. The original schedule focused on 0.35μm and 0.25μm technologies as defined by the contract. In 3Q94, the contract was re-phased to concentrate on 0.25μm and 0.18μm x-ray technologies, and the Validation Plan was updated accordingly. These changes were incorporated into the annual Validation Plan Update, CDRL C001, 94-MMD-LFSC-00084. Other updates were relatively minor, consisting primarily of adding actuals to the schedules and updating the test vehicle.

The annual update for the Validation Plan for year-end 1995 has been submitted (reference CDRL C001, 96-MMD-LFSC-00002).

Figure 2 shows the phase shift validation schedule. The Validation Plan updates covered in the x-ray mask schedule also included updates for the phase shift mask schedule, and therefore, are not shown in this figure.

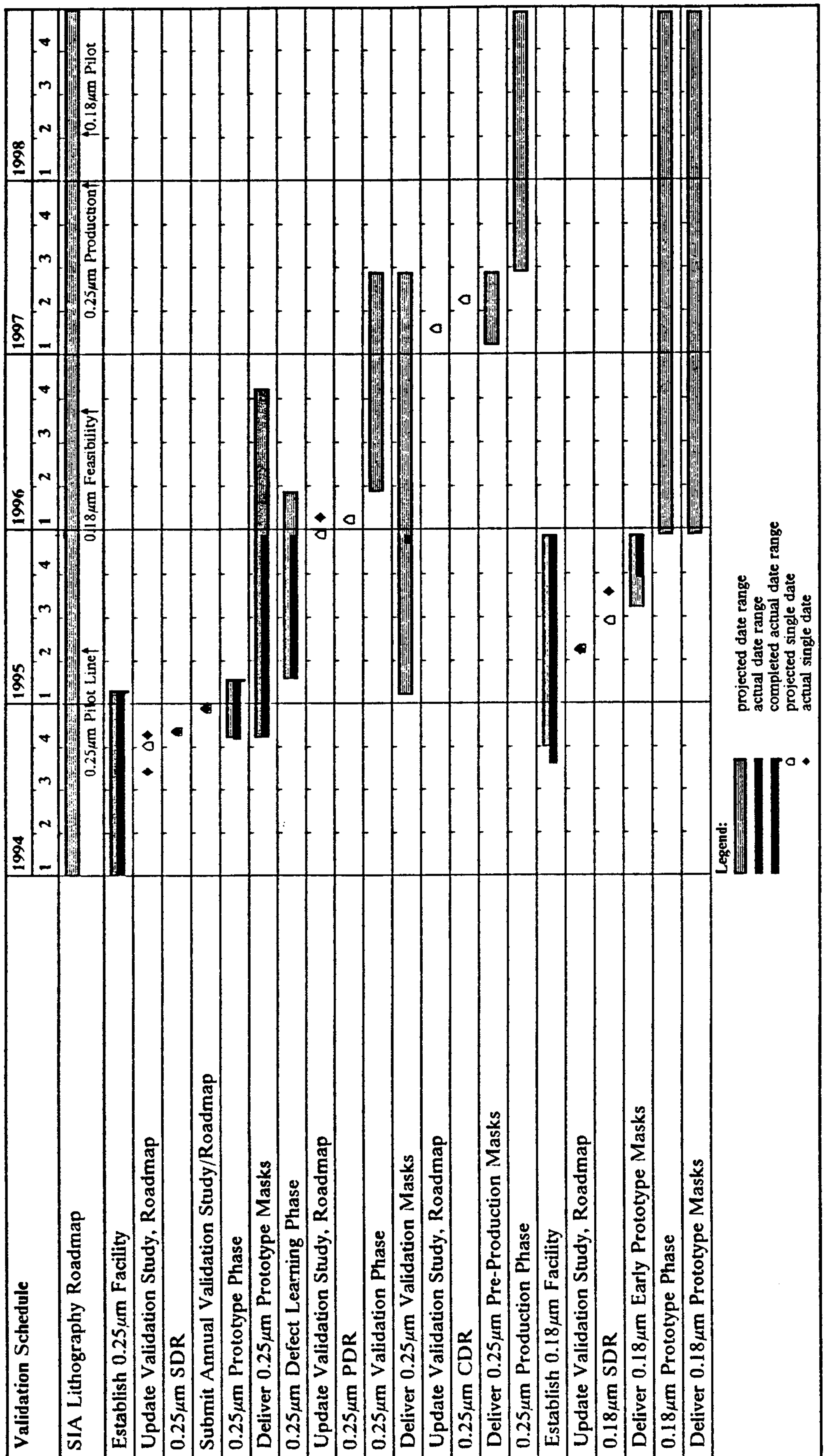


Figure 1. 0.25μm and 0.18μm X-ray Validation Schedule. The schedule for the phases, design reviews, mask deliveries, and plan updates is shown.

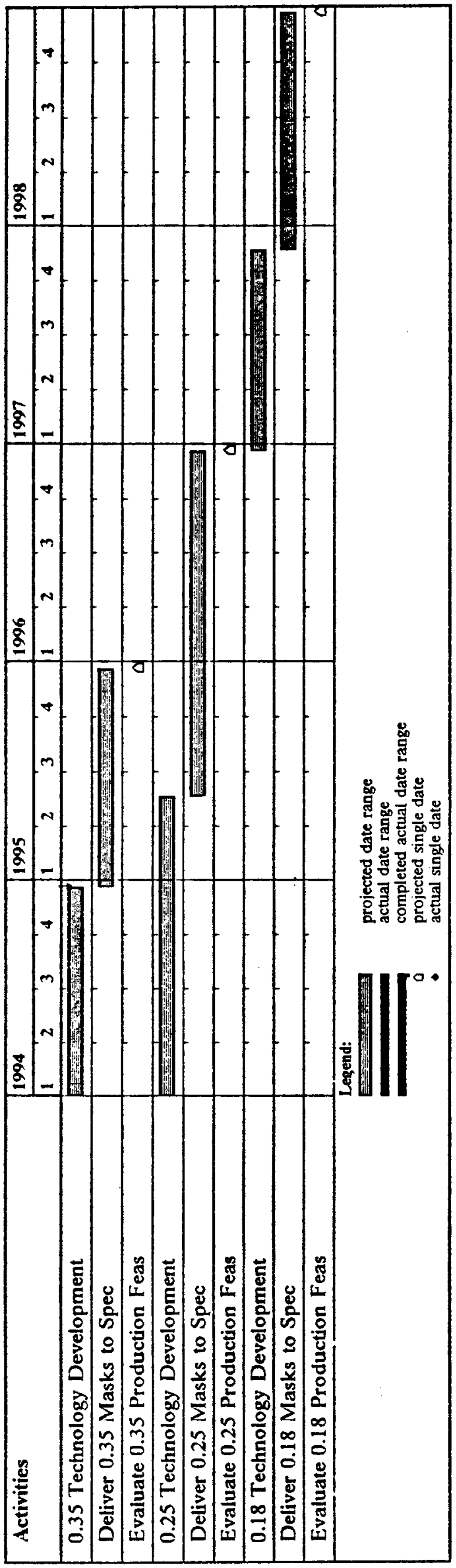


Figure 2. Phase Shift Validation Schedule

2.2 Test Vehicle Description

2.2.1 EXPO, TALON and NIGHTHAWK

Characteristics of the MMD test vehicles can be seen in Table 1. The aggressive challenge of x-ray mask building is evident from this table. Beginning with EXPO and progressing to NIGHTHAWK, the specifications for image placement, image size control and defects became increasingly difficult, while the chip size and complexity increased.

A detailed description of EXPO, TALON and NIGHTHAWK is provided in MMD CDRL C003, 0.25μm Test Pattern Description.

Image placement, image size and defect results are discussed in Section 4.1.

Table 1. Test Vehicle Summary

Name	Prod Dates	# Chips	Size mm	CD Array nm	CD TSite nm	Mask Levels	IP (3σ) nm	Array IS (3σ) nm	Defects #/cm^2	KLA Sens.	Yield %	All Good Yield %	Starts/ week
EXPO	*10/94-2/95*	*2*	*16Mb SRAM 29.6×11.3*	*350*	*250*	*PC CA,M0*	*60 (120)*	*25*	*N/A*	*120*	*N/A*	*N/A*	*N/A*
TALON	*3/95-6/95*	*1*	*32Mb SRAM 19.4×20.0*	*250*	*180*	*M0*	*120*	*25*	*175*	*200*	*16*	*N/A*	*10*
TALON	*6/95-9/95*	*1*	*32Mb SRAM 19.4×20.0*	*250*	*180*	*M0*	*85*	*25*	*50*	*180*	*16*	*N/A*	*10*
TALON	*9/95-12/95*	*1*	*32Mb SRAM 19.4×20.0*	*250*	*180*	*M0*	*60*	*25*	*13*	*140*	*16*	*16*	*10*
NIGHT-HAWK	*1/95-12/95*	*1*	*64Mb SRAM 30.1×17.8*	*250*	*180*	*M0 (CA)*	*35*	*20*	*10*	*120*	*16*	*16*	*10*

3.0 Roadmap Activities (Task 1)

***Task Objective:** Devise a comprehensive MMD technology roadmap.*

3.1 Technology Roadmap

The Technology Roadmap, CDRL C002, describes the processes, tooling and methodologies required to develop and demonstrate successive generations of x-ray mask fabrication capability. It includes a basic description of the processes and tooling currently in use for x-ray mask manufacture and detailed plans for the production of next generation x-ray masks.

Contract requirements for the Technology Roadmap are similar to the Validation Plan. Updates are required annually and prior to each design review. The schedule for Technology Roadmap updates coincides with the updates to the Validation Plan as shown in Figure 1.

The initial Technology Roadmap included the strategy required for meeting 0.35μm and 0.25μm technologies to the initial contract schedule. In 3Q94, with the re-phasing of the contract as mentioned previously, the Technology Roadmap was changed significantly in order to concentrate on 0.25μm and 0.18μm technologies. These changes were incorporated into the annual update submitted in December, 1994. Other updates were relatively minor, consisting primarily of adding actuals to the schedules and updating the tooling status as new tools were installed, qualified and implemented.

The annual update for the Technology Roadmap for year-end 1995 has been submitted (reference CDRL C002, 96-MMD-LFSC-00003).

3.2 Tool Qualifications and Status

3.2.1 NIST Ring Standard

The NIST ring standard specification was changed on 30 June 1995 to reduce foreign material (FM) contamination and facilitate build, resulting in lower cost for the new design. The details of the changes are discussed in CDRL D004, 2Q95 Progress Report, 95-MMD-LFSC-00051.

3.2.2 Metrology

Amray AutoSEM

The MMD Amray AutoSEM was installed in 1994 and implemented into manufacturing in 1Q95. Tool parameters include precision of 4nm 3σ line pitch and 5nm 3σ linewidth with resolution of 2nm at 20kV and 8nm at 1kV. Micrographs can be taken in either secondary emission mode or transmission mode. The Amray AutoSEM uses extensive automation and intelligent software to perform 100 measurements per hour and generate data reports.

Leica LMS2000 and LMS2020

A Leica LMS2000 is used to measure x-ray mask image placement. The tool features manual load, automatic measurement and reporting. It is >95% reliable and current throughput is eight seconds per measurement. An LMS2020 with potential throughput of five seconds per measurement is currently being installed. This system is discussed in detail in CDRL D004, 2Q95 Progress Report, 95-MMD-LFSC-00051. Table 2 shows a comparison of the tool specifications.

Table 2. Leica Tool Comparison

	LMS2000	LMS2020
Short-term Precision	*12nm* 3σ	*8nm* 3σ
Long-term Precision	*15nm* 3σ	*10nm* 3σ
Accuracy	*25nm* 3σ	*25nm* 3σ

3.2.3 Inspection/Repair

Micrion

The MMD Micrion repair system was installed and qualified during 3Q94. The maximum resolution is 30nm with 18nm edge placement accuracy. The column in this tool is adequate for repair of 180nm linewidth designs. For 130nm linewidth, a new column, currently being developed at Micrion, will be capable of 15nm maximum resolution and edge placement accuracy of 13nm.

KLA

For defect inspection, a KLA SEMSpec 701 features fully automatic SMIF loading, inspection and report generation. The tool boasts >97% reliability with 50nm maximum sensitivity, 0.08 defects/cm^2 per pass, 0.3μm defects added, and throughput of two masks per hour at maximum sensitivity. A second tool was installed in 3Q95 and qualified in 4Q95 for capacity requirements.

3.2.4 Process

Convac Develop Tool

The Convac develop tool was qualified in May of 1995 as a system dedicated for use in the develop process. Previously, the develop process was performed on a system which was shared with another process step. This is discussed further in Section 4.1.5.

Karl Suss Coater

An interim resist apply tool was provided by Karl Suss America for early process learning while a new automated tool was built. The tool was qualified for product during September of 1995. See Section 4.1.5 for a status of the automated tool.

CVC Sputter System for Plating Base

A CVC sputter system was qualified in March of 1995 and running product in May of 1995. This system was implemented for defect improvements. Additional information on the CVC tool is given in section 4.1.4 and in CDRL D004, January 1995 Progress Report, 95-MMD-LFSC-00022.

Helium-Cooled Plasmastherm

A helium-cooled Plasmatherm plasma processing system was qualified for resist strip in October of 1994. Helium cooling was required in order to keep the membrane at low temperatures during the resist strip process, avoiding annealing of the plated gold. It had been determined previously that annealing due to high temperatures caused unacceptable image placement distortions of the mask. More detail can be found in CDRL D004, 1994 Annual Report, 95-MMD-LFSC-00030.

3.2.5 E-Beam Exposure

EL-4 XE P0

The EL-4 P0 e-beam exposure system was installed and qualified in 1995. This system provided significant opportunities for improvement of image size and image placement of the x-ray masks. Qualification results are discussed in Section 4.2.1.

4.0 Develop and Demonstrate X-Ray Mask Fabrication Capability (Tasks 2 and 3)

Task Objective: ***Establish and maintain a pilot production facility capable of on-premises x-ray mask production, and demonstrate mask fabrication capability by fabricating prototype masks of increasing complexity.***

4.1 Line Status - Overview

The 1994 and 1995 line activities focused on establishing the MMD as a manufacturing facility. Statistical Process Control was expanded to encompass all processing. The Manufacturing Control System (MCS) was implemented as the line logistics system. Manufacturing Process Specifications (MPS) and Process Change Notices (PCN) were implemented for document processing.

The MMD received ISO9001 certification in 1993, and semi-annual recertification audits during 1994 and 1995 confirmed continued MMD compliance with ISO requirements. A listing of the ISO9001 requirements and fulfillments was provided in CDRL D00A, Annual Quality Assurance Report, 95-MMD-LFSC-00014.

A mask ordering process was defined and documented in 1994. Details of data handling during mask ordering are documented in CDRL C002, Technology Roadmap.

Image placement results from the individual test vehicle designs for 1995 are shown in Figure 3. Hontas 6 results refer to results from EL-3+ #6; XEP0 results refer to EL-4 P0. The *X* axis shows whether masks were written on thin or thick membranes, with or without PSE, and single or multiple passes (SP or MP). A combination of thick membranes using multiple-pass writing with PSE on EL-3+ #6 resulted in average placement in the 50nm range. The same combination on EL-4 P0 resulted in average placement in the 35nm range.

Image size results are shown in Figure 4 and Figure 5. Figure 4 shows the image size 3σ for each TALON mask produced on EL-3+ #6, regardless of the writing method (single- or multiple-pass). It shows constant learning towards the $0.25\mu m$ validation specification of 25nm. Figure 5 shows the image size 3σ for each NIGHTHAWK mask produced on EL-4 P0. It clearly shows a difference between multiple-pass (MPASS) and single-pass (SPASS) writing. Initially, 35% of the masks were within the prototype specification for multiple-pass writing, while single-pass masks have performed consistently well. Although there has been some modest improvement over time, this problem remains under investigation. Multiple-pass writing is discussed further in section 4.1.3.

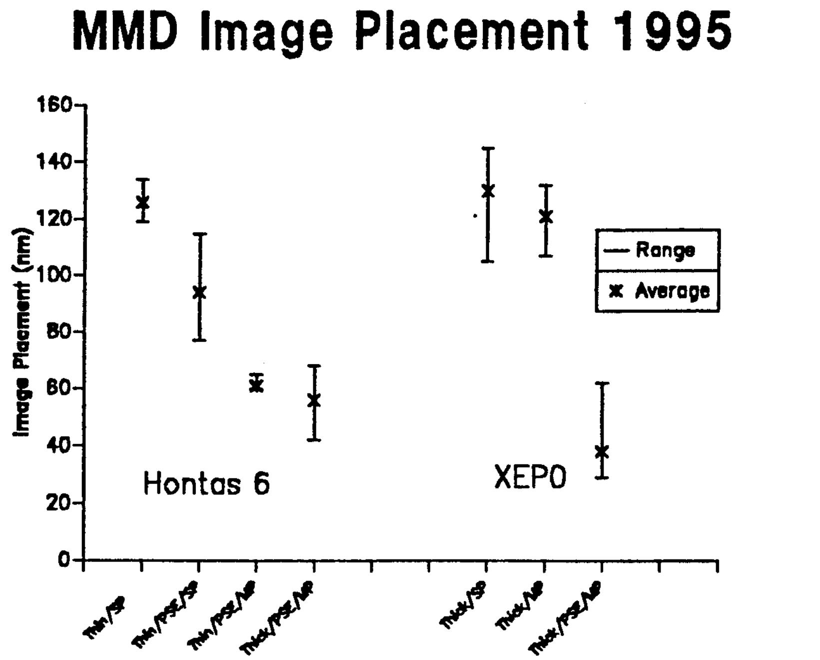


Figure 3. MMD Image Placement, 1995

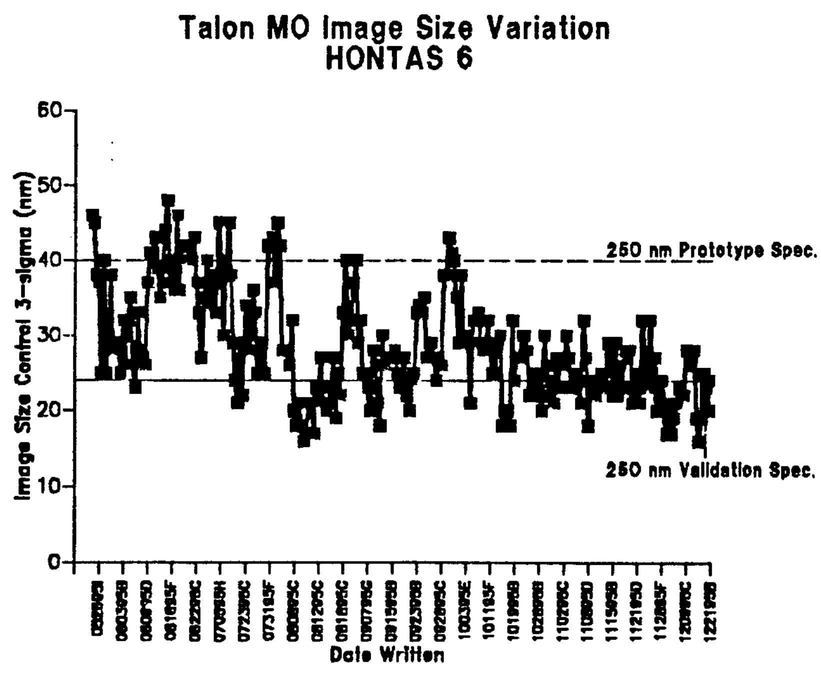


Figure 4. TALON M0 Image Size Variation (EL-3 #6)

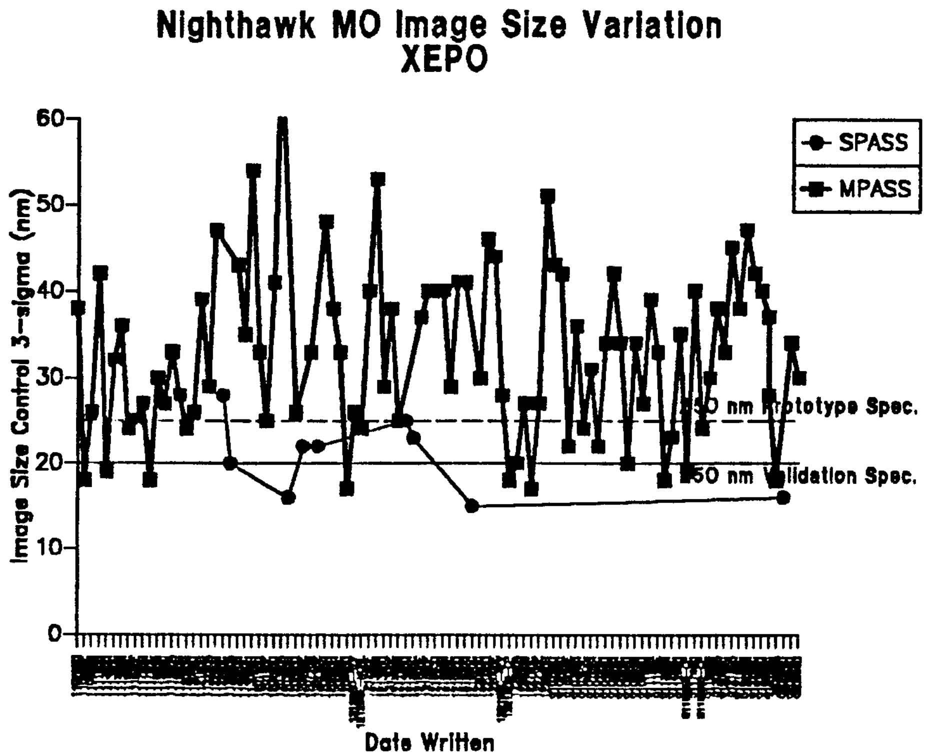


Figure 5. NIGHTHAWK M0 Image Size Variation (XEPO)

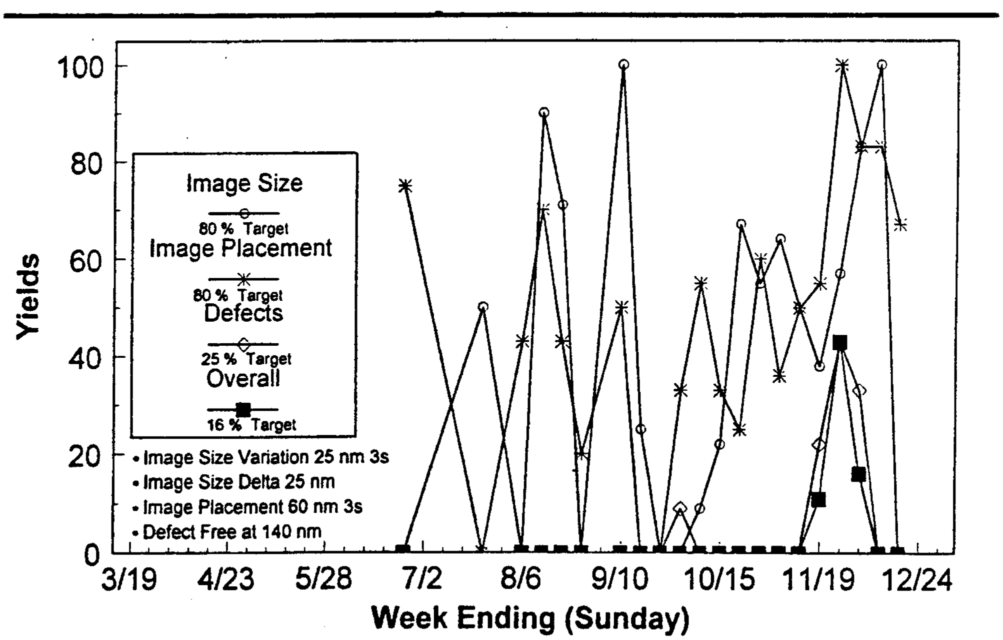


Figure 6. TALON Yield September Checkpoint

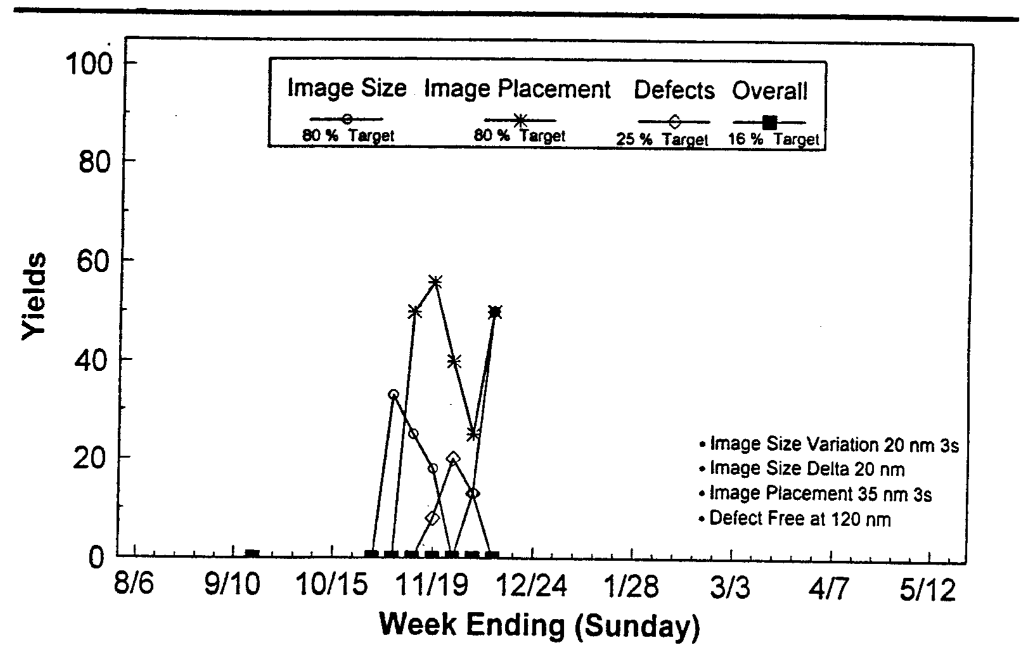


Figure 7. NIGHTHAWK Yield December Checkpoint

4.1.1 MMD Mask Deliveries

One-hundred twenty masks were shipped during the contract period: 14 Motorola designs, 14 EXPO, 19 NIGHTHAWK (prototype), two NIGHTHAWK (validated), 63 TALON, four SVGL test sites, two LSU test sites, and two Lockheed designs.

Of the masks shipped, four NIGHTHAWK masks have been manufactured with zero defects off EL-4 P0, bringing the total number of defect-free TALON/NIGHTHAWK mask shipments to 12. There are five TALON mask shipments that met the September "triple-point" target for image size, image placement and defects.

4.1.2 E-Beam Performance and Image Placement Results

For most of 1994, EL-3+ #6 exposed product at 50kV. Product types for the first half of the year included LIGHT25, Motorola and an IBM 64Mb DRAM chip. Product Specific Emulation (PSE) was used for LIGHT25 and 64Mb DRAM, but not for Motorola jobs which were less complex. Image placement error generally measured approximately 70nm for these products.

EXPO was written predominantly in the last half of 1994. A PSE was created on EL-3+ #6 and the average image placement error was 65nm. In the same time frame, EL-3+ #12 was converted to 75kV to obtain better resolution of 250nm linewidths and for better image quality. Product was transferred to EL-3+ #12 at the end of the year to obtain this better image quality, but at the expense of image placement. Both the stage and the chamber of EL-3+ #12 are inferior to EL-3+ #6. Very crisp 250nm and

180nm lines were resolved for EXPO on this system, but image placement error ranged from 90-170nm.

At the beginning of 1995, the decision was made to convert EL-3+ #6 to 75kV to obtain better image quality and resolution along with the steady image placement performance. The conversion was completed in March. Image size was larger than expected and by July the dodecapole was changed to eliminate a charging problem. In late summer 1995, the Y-drive Rohlix that affects table moves was fixed and defective NIST leveling screws were found and repaired.

Also in the beginning of 1995, TALON and NIGHTHAWK became the MMD line monitors, with the majority of the exposures at EL-3+ #6 being TALONs. TALON image placement error averaged 65nm throughout the second and third quarters of 1995.

Three major breakthroughs in the fourth quarter helped MMD reach the validated MMD specifications. First, the conversion from 2.5μm to 5.0μm thick membranes reduced TALON image placement average with PSE from 65nm to 60nm. Multiple-pass writing with PSE was implemented on EL-3+ #6 in October, and TALON image placement was reduced even further to an average of 45nm with parts as low as 35nm. Finally, EL-4 began product exposures in earnest and was able to average 35nm image placement on the larger NIGHTHAWK monitor with parts as low as 29nm. These changes are discussed in detail in the following sections.

Tool use for all e-beam systems for the past 24 months is depicted in Figure 8.

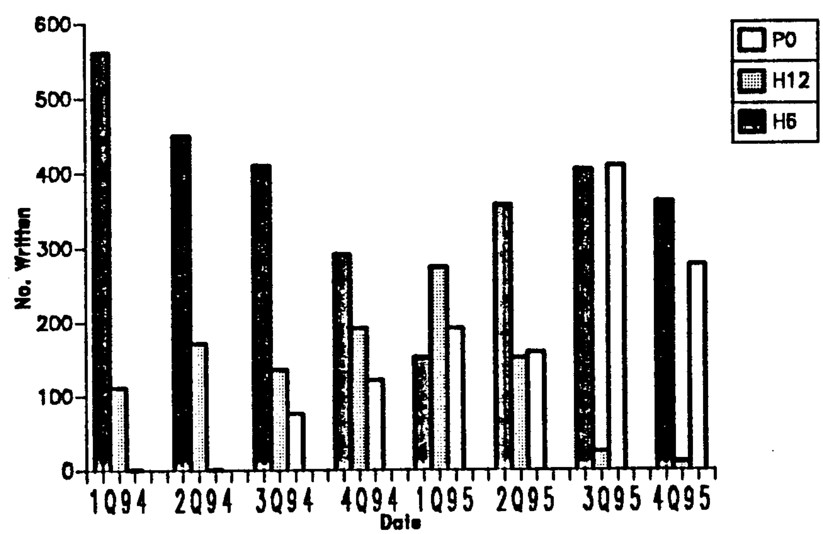


Figure 8. E-Beam Exposures

4.1.3 Miscellaneous Image Placement Experiments

Multiple-Pass Writing

Multiple-pass writing has been optimized and implemented. An initial evaluation was completed on EL-3+ #6 in accordance with Task 8, Technology Acquisition (reference CDRL C007, Technology Assessment Report, 94-MMD-LFSC-00072). This evaluation showed that multiple-pass writing was desirable for image placement reasons, but required significantly more defect and image size optimization before implementation. Optimization was completed in November of 1995, and the procedure was implemented for product. Image placement yield on EL-3+ #6 to 0.25μm prototype specifications significantly improved from less than 50% to greater than 90% with no detrimental effect on image size and defects (a portion of the improvement was due to thick membranes, discussed in the next section). This was accomplished by using five passes of exposure at 1/6 dose each for 83% total dose.

The technique was transferred to EL-4 P0, with image placement results of <35nm 3σ on final masks. However, although image size control on EL-4 P0 has been very good for single-pass exposures, multiple-pass results have been somewhat erratic. The implication is that the pattern experiences small positional shifts between passes which cause linewidth variations. It appears, however, to be a small instability since image placement measurements are consistently excellent. Sources of the erratic image size performance are currently under investigation.

Process-Induced Distortion in X-ray Masks

During the end of 1994 and early in 1995, an analysis of the process contributions to image placement was completed. The details of these activities can be found in CDRL D004, January 1995 Progress Report, 95-MMD-LFSC-00022 and CDRL D004, 2Q95 Progress Report, 95-MMD-LFSC-00051. In summary, the contributions of gold electroplating, resist strip and plating base removal were determined. The plating base removal contribution was eliminated by implementing a selective plating base removal process in which only the alignment mark areas, rather than the entire mask, are stripped of plating base. Zero level masks known as BOXTEST were used for resist process characterization. BOXTEST showed that during e-beam exposure, most of the resist film stress is relieved. This result prompted additional work to understand and correct for this movement:

- Modeling of the distortions due to resist stress relief was initiated with the University of Wisconsin. This project is ongoing.
- The polymer length effect on PMMA resist stress was investigated. Polymer length relates to molecular weight. As molecular weight was varied from 33k to 950k atomic mass units, no ***significant*** differences in film stress were found.

- Continuing investigation showed that 50% stress relief occurs with a very low exposure dose. This prompted a study of the use of a blanket pre-exposure to minimize the stress relief (and therefore membrane movement) during exposure. An initial process using UV pre-exposure caused standing waves and could not be used. To date, e-beam pre-exposures have resulted in unacceptably large image size. Both pre-exposure processes had significantly different image placement characteristics than normal masks and the BEOL distortion was approximately half, indicating some resist stress relief from the pre-expose. Work on this project is continuing.

Since very few process changes resulted in improvement to the process-induced distortion, efforts were shifted to stiffening the membrane. The ultimate solution is a switch to silicon carbide as the membrane material, which is planned for 1996. In the interim, thicker boron-doped silicon membranes were implemented. As mentioned in the 2Q95 Progress Report, initial placement on a small sample of 5.0μm membranes was $\simeq$50% better than on 2.5μm membranes with no additional processing. The thick membrane process was implemented on TALON and NIGHTHAWK substrates in late September, 1995. For TALON product written on EL-3+ #6, about 10% of the image placement improvement came from implementing thick membranes (image placement was 60nm on TALON during September through November, 1995 compared to 65nm during May through September, 1995). The combination of thick membranes and multiple-pass writing on EL-4 resulted in <35nm 3σ image placement on NIGHTHAWK.

4.1.4 Substrate Fabrication (FEOL)

In early 1994, mask orders were filled from "build ahead" supplies of substrates. With the establishment of tracking systems and routine ordering procedures, a build-to-order production control system was implemented in 2Q94, minimizing the number of rings and membranes used.

1995 was a year of defect reduction for the FEOL team. Defect categories (see CDRL D004, January 1994 Progress Report, 94-MMD-LFSC-00008) were established and many ideas were evaluated to reduce handling and defect contribution.

To support defect requirements, a CVC sputter system was converted for use with the chrome/gold plating base deposition process. The CVC, new in 1990, was found to be an improvement over the Balzer evaporator. When compared to the Balzer, foreign material levels were reduced by as much as 80%, uniformity was twice as good and film stress was comparable. Information is available in CDRL D004, January 1995 Progress Report, 95-MMD-LFSC-00022.

The mask identification number, which had been scribed on the front surface of the mask, was moved to the back, reducing front-side FM by as much as 15%.

The inspection tool (QCO) used in the post-bond sector was upgraded by removing pins that held the mask on the front side and replacing them with a new fixture. During the September, 1995 time frame, a piranha clean (strong acid clean) after plating base deposition was implemented and reduced the number of 10μm and larger defects by approximately 77%.

In the ring bonding area, ring cleaning and flame polishing (part of NIST document change, reference CDRL D004, 2Q95 Progress Report, 95-MMD-LFSC-00051) reduced the ring contribution of particulates. On 08 December 1995, dedicated ring shipment containers were implemented with the intention of reduced handling and packaging by the ring manufacturer. The bonder clamping fixture and surface coating have been evaluated, and minor mechanical changes have provided some improvements.

Implementation of new mask carriers, improved raw-wafer quality, modifications to the membrane etch station, the addition of argon to the boron diffusion process, and additional cleaning have all contributed to improved substrate quality and are discussed in detail in CDRL D004, 2Q95 Progress Report, 95-MMD-LFSC-00051 and CDRL D004, 3Q95 Progress Report, 95-MMD-LFSC-00085

4.1.5 Photoresist

<u>Convac Develop Tool</u>

The PMMA develop process evolved from a laboratory procedure to a dedicated Convac solvent-develop system. The Convac develop tool was qualified in May of 1995 and has significantly reduced defect density.

Foreign material (FM) was reduced from 700 particles to <20 by 4Q95. The average for the quarter was 11.4 particles added per wafer. Corrective actions taken to achieve this improvement include the replacement of several chemically incompatible components of the tool, use of distilled rather than deionized water, and creation of a solvent atmosphere with a small beaker of isoamyl acetate below the nozzle to prevent residue formation. Solvent cans are kept full at all times and Teflon™-lined solvent cans have been received for evaluation. Details of the Convac develop tool improvements are shown in Figure 9.

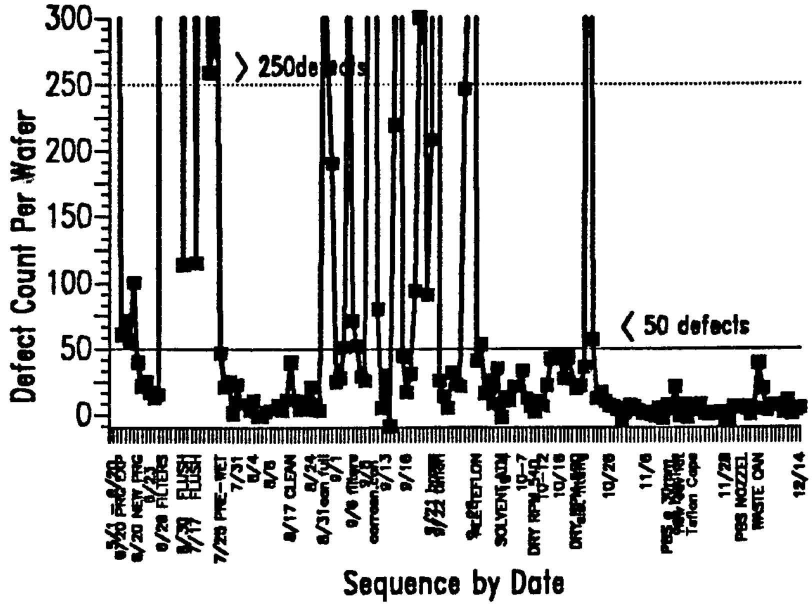


Figure 9. Convac Develop FM Time Line. Light point defects $</= 0.25\mu m^2$, May-December, 1995.

New Karl Suss Coater

A new Karl Suss resist coat tool was ordered. This tool uses a cover during the spin process in order to keep a solvent-rich atmosphere over the coating, resulting in improved resist thickness uniformity. As mentioned in Section 3.2.4, an interim system was implemented for product during 3Q95 while a new automated system was fabricated.

Pre-acceptance testing of the automated coat tool was conducted at Karl Suss in Waterbury, Vermont from 12-15 December 1995. The reliability test revealed an intermittent positioning problem with the Cybec™ robot, possibly caused by the motor. The software for the robot is designed for an insufficient number of positions to handle both wafers and x-ray membranes. The tool is currently aligned for membranes only. A software fix will be available in February 1996. The edge-rinse configuration was unacceptable due to the position (angle) and size of the nozzle.

The resist thickness uniformity on monitors was between 45 and 100Å versus the specification of 25Å. Process optimization is underway in an effort to meet the specification. However, due to a lack of environmental control (humidity and particulate) at the factory, this optimization will be completed after the tool is installed at the MMD.

The factory acceptance test was completed and the tool was shipped to the MMD in January 1996.

Carbon Room

In 1994, the performance of the chemically-amplified negative resist was unacceptable because of sensitivity to airborne chemicals in the parts-per-million range. A special room with carbon filtering to eliminate NMP (N-methyl-pyrolidone) was designed to house the resist coat tools in order to minimize airborne contamination. This work began in 1994 and was completed during February, 1995. As reported in the 2Q95 Progress Report, the amount of NMP detected in the carbon room is <0.012ppm, less than the limit of the analytical test.

PMMA

In 1994, PMMA positive resist was evaluated for e-beam patterning. This resist is well-characterized in the literature and offered improvements in linewidth and resolution as well as chemical stability. The disadvantages of PMMA are that its sensitivity to e-beam makes it impossible to characterize SEMs of resist images, and it is not etch resistant. It is acceptable for use in conjunction with an additive process such as our gold electroplating process, but cannot be used with a subtractive process, such as the refractory-metal absorber process. A complete report on PMMA was delivered under CDRL C007, Technology Assessment Report, 94-MMD-LFSC-00086.

PMMA was implemented for product in 1995 and focus was switched from process development to defect optimization. Several sources of defects were identified and eliminated, resulting in the manufacture of defect-free masks. Work continues with PMMA defect reduction and film stress reduction.

4.1.6 BEOL Foreign Material and Inspection

In 1994, the BEOL implemented numerous manufacturing measurements to track performance. The task of converting the AMF development line into the MMD manufacturing line began with implementation of paperless statistical control systems. From 01 October 1994 to the end of 1994, 250 masks were plated in the BEOL. In 1995, about 1,000 masks were plated in the BEOL, and specific problem areas were identified and fixed. The following activities were discussed in detail in the quarterly progress reports.

- Spots from the plating base removal tool were eliminated by frequent tool cleaning (reference CDRL D004, January 1995 Progress Report, 95-MMD-LFSC-00022).
- A new clamping system for the Plasmatherm eliminated residual resist and plating base defects (reference CDRL D004, January 1995 Progress Report, 95-MMD-LFSC-00022).

- Incoming plating bath was found to be unfiltered. Work continues to improve the quality of the MicroFab Au-510™ chemical from the vendor. CDRL D004, January 1995 Progress Report, 95-MMD-LFSC-00022 contains details of this work. Changes were made to the packaging to make it clean-room compatible (card-board was eliminated and a new solid polyethylene bottle was implemented). Sel-Rex is now filtering the solution, but further improvement is still needed. The MMD is filtering the solution to less than one particle per milliliter.
- The Micrion repair area was identified as a source of contamination. The upgrades for improvements were made by installing two overhead HEPA filter modules. The filter over the Micrion tool creates a class 10 environment which will aid in the continued fabrication of defect-free masks. As device geometry size is reduced, a class 10 environment is critical.
- Gold bubbles, plating station defects, and opaque spots are discussed in CDRL D004, 2Q95 Progress Report, 95-MMD-LFSC-00051. In general, these defects were discovered by routine inspections and solved with tool cleaning and process improvements such as larger pumps, additional filters, or new tooling such as the interim Suss coater.
- A new mask shipping box design was reported in CDRL D004, 3Q95 Progress Report, 95-MMD-LFSC-00085. Rapid Manufacturing has been chosen to design and build a mold for the new mask shipping box, and is expected to be building new mask boxes in 2Q96.
- During 4Q95, a liquid particle counter characterized the rinse process after gold plating. By increasing the D.I. rinse water process time from five minutes to fifteen minutes, an estimated 25% increase in yield was obtained by eliminating stain defects.
- A significant effort has begun in the area of final mask cleaning, including evaluations of new techniques such as a laser ablation system, cryogenic mask cleaning, and upgrades to our current tooling. A chemical spray rack for the megasonics tool has arrived and an evaluation is currently underway.
- Other activities during 1995 included mask handling reduction, inspection tool FM reduction, single SMIF pod evaluation and resist strip foreign material reduction.

4.2 Validation Mask Capability

A significant amount of work has occurred in all sectors, resulting in minimization of defects and improvements to image placement and image size. However, the greatest contributor to reaching the validation specifications for image placement and image size was the installation and qualification of EL-4 P0. Much of the information on EL-4 P0 has been documented in the quarterly reports. Many of the resist experiments have also been documented in the quarterly progress reports. The following sections contain a summary and status of these projects.

4.2.1 Status of EL-4 P0

In December 1994, a new (phase 3) data path improved data handling and processing. It was also found at this time that image quality and placement were unacceptable. Work in the P0 area found contamination on the shaping apertures. Filters on the pump lines and new apertures helped return image size to normal. A team of engineers from IBM, Loral and Motorola was assigned to conduct weekly reviews and system audits to address tool and process problems and define corrective actions. Efforts were established in five phases: to baseline the tool, recommend upgrades, qualify the tool, develop processes/deliver masks and an upgrade to 100kV. This activity was discussed in detail in CDRL D004, 1Q95 Progress Report, 95-MMD-LFSC-00042

Baseline was established for NIGHTHAWK on bonded wafers with 75% image placement yield below 40nm 3σ. Linewidth variations on a membrane were $\simeq$25nm 3σ without "bow" (see below). Because of poor image quality, 0.18μm lines could not be measured. The 0.18μm lines were improved with tool upgrades which included the removal of two column parts.

EL-4 P0 qualification results are discussed in CDRL D004, 3Q95 Progress Report, 95-MMD-LFSC-00085. The qualification ran uninterrupted from 24 July to 4 August 1995. The yield results for image placement were 0% below 25nm and 50% below 35nm 3σ for NIGHTHAWK patterns on bonded wafers in Shipley resist. The mean image size on membranes was 189-202nm for 180nm lines with 11-14nm 3σ image size control across the tool field.

Efforts since then have been focused on optimizing the image size mean and improving image placement. By the end of October, with the implementation of multiple-pass write and automatic registration (AUTOLEARN) between passes, image placement accuracy was improved to 25nm 3σ on bonded wafers and 35nm on final gold membranes with NIGHTHAWK patterns, some with zero defects. From July 1995 through November 1995, 464 masks were written on EL-4, averaging 93 masks per month with a two-shift operation.

Other tool improvements have included replacement of both shaping apertures, elimination of a random spot-shifting problem caused by noise from the magnetic deflection circuits, and elimination of leakage current during servo cycle by shaping the beam to zero coincident with beam blanking.

Also, fogging has been minimized by modifying the carriers on EL-4 P0. CDRL D004, January 1995 Progress Report, 95-MMD-LFSC-00022 included a description of the "bowing" character of image size when plotted across a membrane. Several experiments, including develop spray configuration, apply tool, and descum, were found to have no significant effect on image size variation or "bow." An investigation revealed that the "bow" character was caused by fogging on the e-beam tool. Fogging is caused by electrons that pass through the membrane which are scattered back from the stage surface and pass through the membrane again. A method of eliminating the bow entirely is currently under investigation.

Although work on both image size and image placement will continue, we consider the tool in Phase 4 status. We are routinely exposing 10 NIGHTHAWKs and some TALONs and EWRs each week, with 35nm 3σ image placement on approximately 50% of NIGHTHAWKs in final gold. As mentioned previously, the image size 3σ varies between 18 and 42nm and requires further investigation.

4.2.2 Shipley Resist Status

During the fourth quarter of 1994, an exposure dose matrix was completed to determine the proper dose for Shipley resist at 75kV. Part of the NIGHTHAWK CA was used as the test vehicle. The results were reported in CDRL D004, 1Q95 Progress Report, 95-MMD-LFSC-00042, indicating that the required dose is $14\mu C/cm^2$. Three of four NIGHTHAWK masks met the validation specification for x-bar of 25nm and the prototype specification of 40nm for 3σ (for the 225nm images).

This resist contained dye which precipitated out as the resist aged. A split lot of resist with dye versus the no-dye formulation indicated the resist with no dye has equivalent image size performance to the resist with dye. Consequently, the no-dye resist was implemented.

After the first quarter of 1995, efforts on Shipley were discontinued due to the emphasis on meeting the image size commitments for TALON and NIGHTHAWK using PMMA. However, a Motorola mask and a Lockheed mask were manufactured using Shipley resist and shipped in conformance to customer requirements.

5.0 Technology Acquisition (Task 8)

Task Objective: ***Evaluate the applicability and utility of new technology and tools to use in the MMD pilot production lines with the objective of improving production efficiency, quality and profitability, and achieving progressively smaller mask feature sizes.***

5.1 Alignment Window Improvements Using Silicon Nitride

Silicon nitride is a possible replacement for polyimide for alignment mark window fabrication. Polyimide limits the use of mask cleaning chemicals, and the polyimide process contributes defects. Silicon nitride is considered a possible replacement because it cleans easily and has good optical transmission properties. Initial films from IBM Yorktown were of poor stress and uniformity. This project has been suspended while work on silicon carbide continues.

5.2 Silicon Carbide

During the third quarter of 1995, silicon-carbide films provided by Hoya Corp. and Fujitsu Ltd. were compared and evaluated. Only the polished films from Fujitsu could be inspected for defects and measured for image size. All Hoya samples of deposited silicon carbide had surface roughness which caused difficulties during measurements and inspections. From an image placement standpoint, the Fujitsu 2.0μm polished silicon carbide is much better than IBM's normal 2.5μm boron-doped silicon, and equivalent to 5.0μm IBM boron-doped silicon. Conclusions from the initial study are discussed in CDRL D004, 3Q95 Progress Report, 95-MMD-LFSC-00085. Additional samples were provided by Fujitsu during 4Q95 and several finished Talon masks were fabricated. One of the masks built with the new Fujitsu samples was defect-free and also met image size and image placement specifications; it was shipped as a contract deliverable. Details of the comparison study are discussed in CDRL C007, Technology Assessment Report, 95-MMD-LFSC-00073.

One-hundred additional samples of Fujitsu silicon carbide have been ordered. During 4Q95, Hoya provided MMD with eight additional polished silicon carbide samples for evaluation.

5.3 Motorola Plating Process Evaluation

An evaluation of the Motorola gold plating process using a thallium brightener was completed; there was no significant improvement over the process of record (arsenic brightener). Process-induced distortion from parts plated in the Motorola gold plating process was worse and gold thickness uniformity was the same as MMD-plated parts.

Based on this, the Motorola plating process was not implemented. Details are given in CDRL D004, 2Q95 Progress Report, 95-MMD-LFSC-00051, and CDRL C007, Technology Acquisition Report, 96-MMD-LFSC-00015.

5.4 On-Substrate Registration and Grid Techniques

This technique places a reference mark on the substrate which is "revisited" during the write process to remove drift. On EL-3+ #6 it was found that the drift was comparable to tool noise resulting in no benefit from using this technique.

The results of this evaluation can be found in CDRL C007, Technology Assessment Report, 95-MMD-LFSC-00071.

5.5 Multiple-Pass Writing

Multiple-pass writing was evaluated and implemented for significant improvement to image placement. This is discussed in Section 4.1.3, and the initial evaluation results can be found in CDRL C007, 95-MMD-LFSC-00072.

5.6 Evaluation of Leica E-Beam Lithography Tool

Meeting the specifications for x-ray masks requires the highest performance from e-beam lithography tools, first because x-ray needs 1× printable masks (no reduction of features), and second because it is targeted for future product, i.e., 0.13μm geometries and below. An evaluation was initiated to benchmark the advanced Leica system and determine its applicability for x-ray mask applications.

Our study concluded that in order to perform a complete evaluation of the Leica Vectorbeam system relative to x-ray mask-making requirements, a complete tool capable of processing and exposing a complex pattern, such as NIGHTHAWK in a controlled environment, would be required. Leica has not yet built a system of this type. Various experiments were designed to demonstrate capability with existing systems, but, as expected, some were successful while others were inconclusive. The full Leica system evaluation is reported in detail in CDRL C007, Technology Assessment Report, 95-MMD-LFSC-00084.

A TIM was held on 24 August 1995 to develop a common platform specification for an advanced e-beam system. The minutes of the meeting are documented in CDRL D002, 95-MMD-LFSC-00060.

5.7 Image Size Evaluation of Suss Resist Coater

An image size assessment of the Karl Suss interim tool was completed during August, 1995. The results indicated that although the resist thickness uniformity was greatly improved, there was not a significant change in image size variation. The results have been documented in CDRL C007, Technology Assessment Report, 95-MMD-LFSC-00086.

6.0 Technical Interchange Meetings (Task 10)

***Task Objective:* Conduct Technical Interchange Meetings for industry and the government on a bimonthly basis.**

The Technical Interchange Meetings (TIM) listed below were held during 1994 and 1995. A complete accounting of each meeting, including summary, action items and list of attendees, was submitted in accordance with CDRL D002, Technical Interchange Meeting Minutes. Presentation materials were distributed at the meetings.

- MMD Kick-off Meeting

  This TIM was held on 23 February 1994 at Loral Federal Systems' (LFS) Manassas, Virginia facility. Technical presentations were made reporting on LFS' plans and progress to date on the tasks funded under the MMD contract Statement-of-Work. Reference CDRL D002, 94-MMD-LFSC-00011.

- Design for Manufacturing Workshop

  This was the first of two TIMs on the subject of design for manufacturing. The meeting was held at IBM's Burlington, Vermont facility on 08 March 1994. This workshop was intended as an open forum to address the technical issues embodied in the management of the various data formats and subsequent processing of that data for x-ray mask manufacturing. Each company represented at the meeting reported on their company's current data network, software and hardware, as well as the design practices 'traditionally' employed. Reference CDRL D002, 94-MMD-LFSC-00015.

- X-ray Mask Validation Plan and Roadmap

  This two-day TIM was held at IBM's East Fishkill, New York facility on 21 and 22 April 1994. The 21 April session was devoted to technical presentations reporting on LFS' plans and progress to date under the contract Statement-of-Work. The second session, on 22 April, consisted of a four-hour presentation on the Phase Shift Mask program plans and progress under the contract Statement-of-Work. Reference CDRL D002, 94-MMD-LFSC-00031.

- X-ray Design for Manufacturing Workshop II

  A TIM was held at Motorola in Austin, Texas on 24 June 1994 to address data issues; this was a follow up to the Design for Manufacturing Workshop held on 08 March in Burlington, Vermont. Presentations included summaries of updates and enhancements to the latest EL-3+ post-processor version and to the NIAGARA software. The remainder of the workshop was dedicated to "brainstorming" and outlining possible solutions to the rounding problem during conversion from GDSII to GL-1 data formats. Reference CDRL D002, 94-MMD-LFSC-00048.

- Optical and Phase Shift Mask Inspection

  This TIM was held at KLA in Santa Clara, California on 12 September 1994 and was a follow-up to a previous review that highlighted optical and phase shift mask inspection as an area where no closed plan exists for the 0.25μm and 0.35μm technologies. The main objectives of the meeting were to review current roadmaps and define projected capabilities for advanced chrome-on-glass (COG) and phase shift optical masks, to review industry requirements and gain concurrence on specifications/timing, to identify areas of closure and non-closure, and to make recommendations and define follow-on activities. Reference CDRL D002, 94-MMD-LFSC-00070.

- Die-to-Database Inspection Requirements

  The purpose of this TIM was to discuss industry requirements for an advanced die-to-database inspection of x-ray masks, advanced chrome masks and phase shift masks. The meeting was held at KLA's Santa Clara, California facility on 13 September 1994. Reference CDRL D002, 94-MMD-LFSC-00067.

- MMD Executive Review

  This meeting was a half-day TIM held on 03 November 1994 at IBM's Burlington, Vermont facility. It consisted of technical presentations reporting on Loral Federal Systems activities and status to date on the tasks funded under the contract Statement-of-Work. Reference CDRL D002, 94-MMD-LFSC-00078.

- E-Beam and Silicon Carbide Activities

  A TIM on e-beam and silicon carbide activities was held on 07 March 1995 at IBM's T.J. Watson Research Center in Yorktown Heights, New York. The meeting was conducted in two sessions: the first was a review of the activities, status and future plans of the Burlington e-beam tool, and the second introduced the silicon carbide activities to date and reviewed the MMD silicon-carbide requirements. The minutes of the meeting were submitted in accordance with CDRL D002; reference 95-MMD-LFSC-00016.

- Mask Lithography Systems

  On 08 March 1995, a TIM was held at IBM's T.J. Watson Research Center in Yorktown Heights, New York, consisting of presentations and discussion of the three x-ray mask lithography systems that are currently considered viable for meeting the MMD national mask house aspirations. The three systems discussed were the ETEC Excalibur, the IBM EL-4 and the Leica/Cambridge Vectorbeam. Attendees at this meeting included government and industry representatives involved in the government's x-ray lithography program. The minutes of the meeting were recorded and submitted under CDRL D002, 95-MMD-LFSC-00019.

- E-beam System Status

  Two TIMs were conducted in August 1995 at LFS' Manassas facility. The first TIM was completed on 23 August and focused on EL-4 P0 e-beam system. A detailed review of the tool features and performance was presented. Reference CDRL D002, 95-MMD-LFSC-00059. The second TIM was held 24 August and focused on developing a common platform e-beam specification that would support the SIA roadmap for 180nm and 130nm designs. Reference CDRL D002, 95-MMD-LFSC-00060. Both meetings were well attended and there was good participation from the attendees.

- Mask Cost Methodology/Assumptions

  A TIM was held on 03 November 1995 at IBM's Burlington, Vermont facility. The objective of this meeting was to establish consensus on cost methodology and base assumptions that can be used for cost-per-mask calculation projections with the advanced mask technology community. Reference CDRL D002, 96-MMD-LFSC-00005.

- U.S./Japan X-Ray Mask Workshop

  This TIM was hosted by NTT and held in Gotenba, Japan from 06-09 November 1995. The overall objective of the workshop was to initiate discussions that could lead to a standard mask fabrication process like that used in the photomask area, and to encourage more international cooperation in the development of x-ray technology. The meeting commenced with presentations by the various U.S. and Japanese companies participating, who described their technology and experience. Four concurrent groups - process, materials, equipment and e-beam - then convened to attempt to identify the best processes, tools, etc. and present a summary of their discussions and cross-company agreements at the end of the workshop. The minutes of the workshop were submitted under CDRL D002, 96-MMD-LFSC-00005.

7.0 Phase Shift Mask Activities

7.1 0.35 μm Phase Shift Optical Mask Fabrication (Task 5)

Task Objective

Demonstrate fabrication of 0.35μm phase shift optical masks.

Primary activities for this task are focused on developing and implementing an I-line attenuated phase shift mask (PSM) technology utilizing embedded shifter materials.

7.1.1 Test Pattern Design

A 0.35μm technology test pattern was designed and submitted for fabrication of attenuated phase shift masks. The patterns represent an array of logic and memory type structures in addition to inspection and repair defect learning vehicles. A follow-on design was incorporated to increase the critical area consistent with defect learning.

7.1.2 0.35μm Technology Mask Deliveries

A total of 39 I-line attenuated masks were delivered. These consisted of three thin chrome attenuated masks, 16 embedded chrome attenuated masks and 20 molybdenum silicide attenuated masks. The thin chrome attenuated technology was used initially for mask deliveries while the embedded chrome technology was being developed. The fabrication process eventually migrated to the molybdenum silicide technology due to defect level improvements and process integration enhancements with this technology. Full specifications were achieved with both the embedded chrome and molybdenum silicide technologies, but the molybdenum silicide technology was deemed more manufacturable. Additional details of these changes are highlighted in the following sections.

7.1.3 Thin Chrome Attenuated Processing

A baseline patterning, etch and metrology process was previously implemented for this technology, and a chrome and phase level inspection process and chrome laser repair process were implemented during the contract period. High defect levels were experienced with this technology, however, due to the backside expose process, and the technology was eventually eliminated when the embedded chrome technology was in place. With the migration to the embedded chrome technology, a significant improvement in defect levels was observed.

7.1.4 Embedded Chrome Embedded Shifter Development

Embedded chrome materials were obtained from Dupont under a Sematech contract. Early work focused on verification of the material and blank properties, and establishing specifications and a stable supply for the incoming blanks. Acceptable transmission and phase uniformity was achieved, and the materials were shown to be optically and chemically stable. Defect levels for the incoming blanks were generally acceptable, but some variability was observed that lead to manufacturing yield losses. A sampling plan was implemented to ensure supplier conformance to the specifications.

A pilot level mask manufacturing process was established consisting of e-beam or CORE laser patterning, RIE film etching, image size and image placement metrology, inspection, and a laser repair process.

The e-beam process was the initial process-of-record for approximately nine months, and the process was then converted to CORE laser patterning where improved image profiles and edges were obtained, in addition to improved image placement control. With the initial conversion to the CORE process, excessive 3σ image size variations were observed due to an *X/Y* offset problem with the CORE tool. An adjustment procedure was added to the process and 3σ values were improved from greater than 100nm to less than 50nm. In addition to the conversion to the CORE tool, a modified embedded chrome RIE etch process was implemented that resulted in a reduction in etch loading and additional improvements in image quality and profiles.

Image size measurements were qualified on the Siscan confocal microscope system. An SEM correlation was completed with the IBM Standards Laboratory and offsets of $+0.15\mu m$ for line measurements and $-0.15\mu m$ for space measurements were established. Image placement measurements were qualified on the Leica LMS 2000 system and referenced to standard binary chrome mask measurements.

Initial inspection evaluations were performed on the KLA 239 HR tool. Inconsistent results were obtained with programmed defect reticles and the focus was shifted to the KLA 331 tool. Unique phase shift inspection algorithms were installed on the tool to allow for light calibration of the attenuated films and detection of transmission defects. Inspections on the 331 tool were performed to a $0.35\mu m$ criteria and the final masks were dispositioned to a $0.5\mu m$ criteria.

A Quantronix laser repair strategy was developed and implemented for the embedded chrome materials. Laser repair was chosen versus a Micrion FIB (fixed ion beam) process due to gallium staining issues associated with the FIB systems. Laser power levels were optimized for opaque defect removal. For clear defect repairs, a laser deposition strategy was implemented only for defects greater than $1\mu m$ from critical feature edges. The current equipment does not have sufficient control of the deposition process to allow for repairs within $1\mu m$ from critical feature edges. An AIMS tool was also installed which allows for verification of questionable defect repairs. In addition, a Quantronix DRS 3 advanced laser repair tool has been ordered, but delivery of this system has been delayed.

A significant effort was focused on defect characterization and defect learning. Resist divots from the develop process were one of the initial major defect types observed. These defects resulted in clear defects on the final processed mask. A pre-rinse and modified final rinse process were implemented at the develop operation and this defect type was eliminated. Develop drying residues were also observed, and these residues resulted in opaque extension and bridge type defects as well as edge roughness on the final patterned masks. Modifications to the drying process resulted in a significant reduction of this defect type, although difficulties in controlling it persisted. A third major defect type observed was foreign material and residuals related to the resist strip operation. This manifested itself in opaque extension type defects. A modified strip process was implemented in conjunction with an SSEC brush clean, and again a significant reduction in the level of this defect type was observed.

Integration of an opaque border and stepper alignment marks was also a key project. Zero E-field gratings were evaluated but deemed to be non-manufacturable due to aggressive tolerances being required on the gratings. A dual layer redeposition process was also evaluated, and although acceptable masks could be fabricated with this process, excessive defect levels and longer turnaround times remained a key problem with this approach. A chrome topcoat process was eventually chosen as the process-of-record when the technology migrated to the molybdenum silicide materials.

7.1.5 Molybdenum Silicide Embedded Shifter Development

Molybdenum silicide materials were evaluated in parallel with the embedded chrome materials. The 0.35μm embedded PSM technology eventually migrated to molybdenum silicide based on improved defect density results and a less complicated integration into the overall mask fabrication process.

Molybdenum silicide materials were obtained through Hoya Electronics and, as with the embedded chrome materials, were evaluated for transmission and phase uniformity, optical and chemical stability, and defect levels. The blanks were acceptable for all of these parameters and actually exhibited lower defect levels than the embedded chrome materials. Committed specifications were obtained from Hoya, and a routine procurement process was set up for obtaining these blanks.

A CORE patterning process was established for the molybdenum silicide materials using a chrome top layer patterning and wet etch process followed by an RIE molybdenum silicide etch process. An initial etch process was established but image size control was a concern due to a non-zero etch bias and non-vertical image sidewalls of approximately 70 degrees. A modified etch process was implemented that reduced the etch bias to approximately zero and improved the image sidewall profiles to greater than 80 degrees. This resulted in a stabilization of the mean-to-nominal image size control, and also an improvement in 3σ image size control of approximately 10nm. When referenced to embedded chrome performance, 3σ performance remained elevated but was within specification.

A Siscan image size metrology process was also qualified for the molybdenum silicide materials, and SEM Standards Laboratory offsets of $+0.21\mu m$ for lines and $-0.25\mu m$ for spaces were established. No change in image placement metrology was observed with migration to the molybdenum silicide materials. Figure 10 and Figure 11 show the image size and image placement performance for the $0.35\mu m$ PSM technology beginning with thin chrome and progressing through the final molybdenum silicide process.

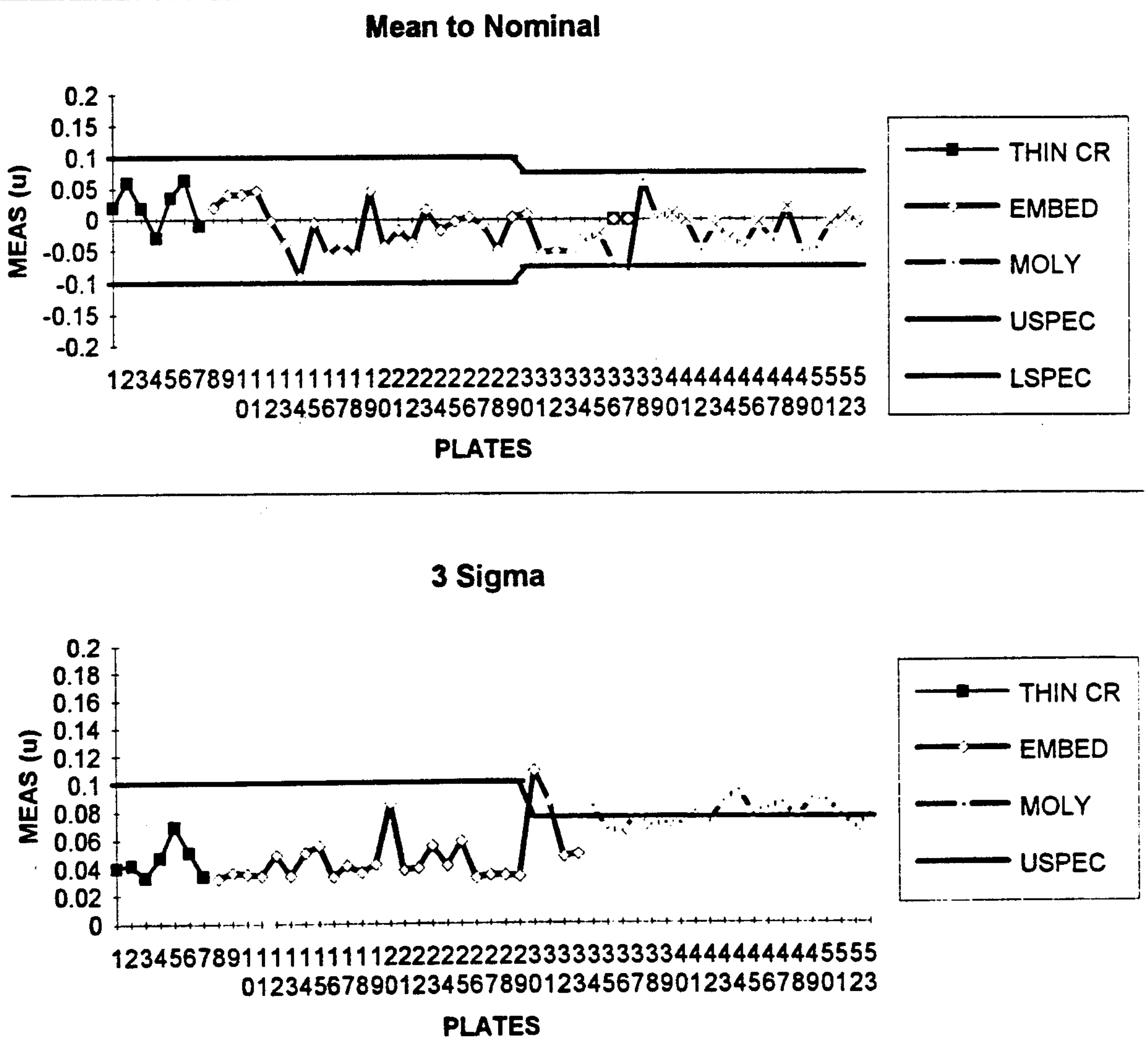


Figure 10. $0.35\mu m$ Embedded Image Size

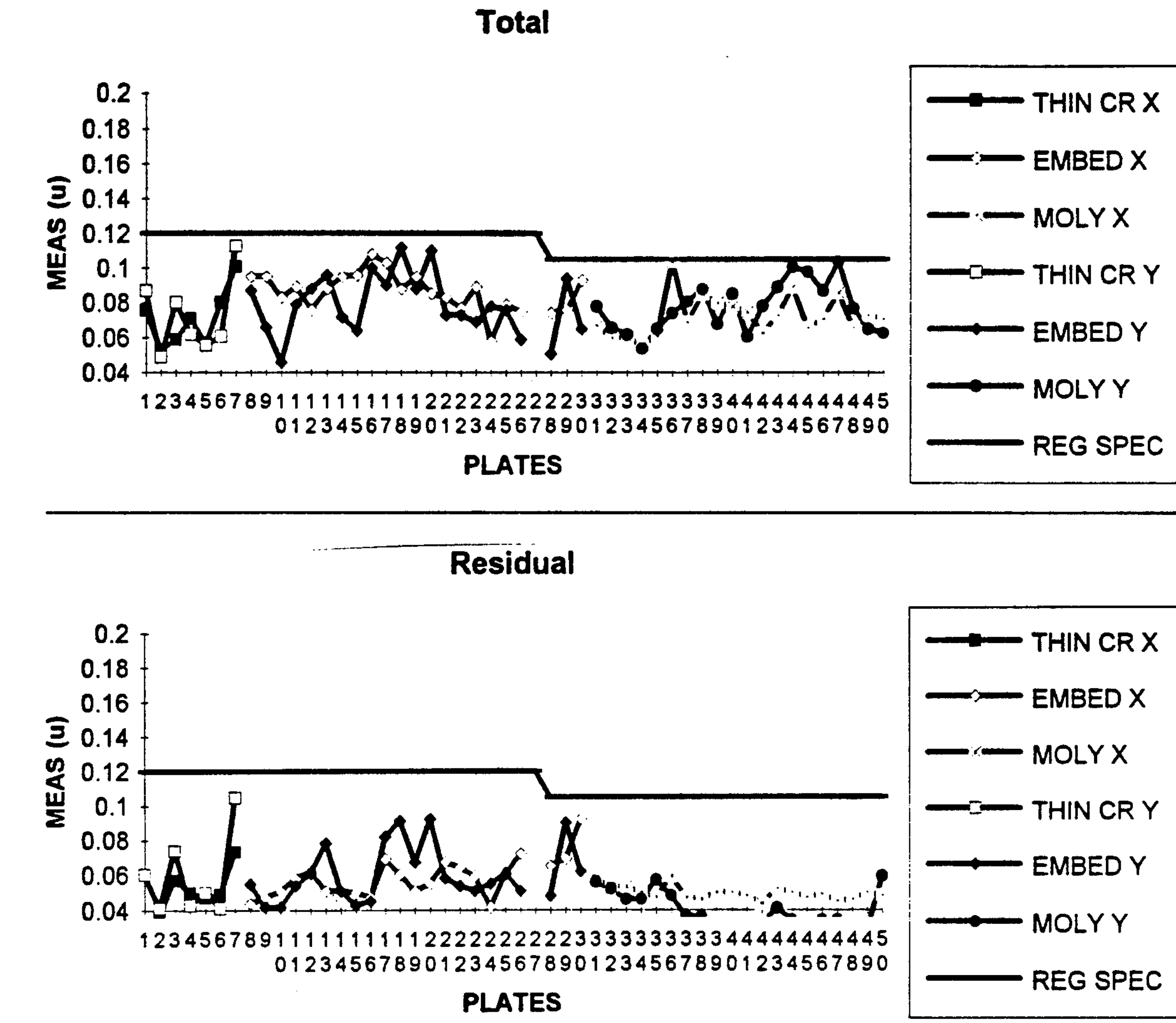


Figure 11. 0.35μm I-Line Embedded Registration

The optical properties of the molybdenum silicide materials at the KLA 331 inspection wavelength of 488nm were similar to those of the embedded chrome materials; therefore, no significant changes to the inspection process were required for molybdenum silicide.

For the laser repair process, the same strategy was implemented for the molybdenum silicide materials as that used for the embedded chrome materials. Laser power levels were adjusted for the molybdenum materials.

A significant reduction in the overall defect level was observed with conversion to molybdenum silicide. Figure 12 shows the defect density performance for the 0.35μm PSM technology for the embedded chrome and molybdenum silicide materials.

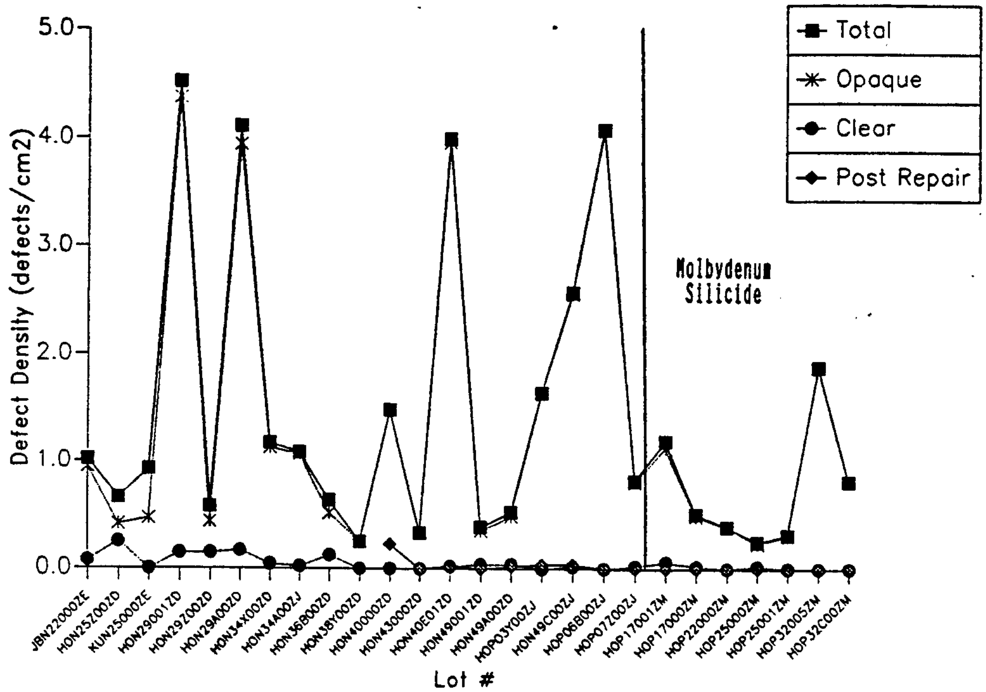


Figure 12. 0.35μm Embedded Defect Density Results. KLA 331 0.35μm Sensitivity/0.50μm Post Repair Criteria

7.2 0.25 μm Phase Shift Optical Mask Fabrication (Task 6)

Task Objective

Demonstrate fabrication of 0.25μm phase shift optical masks.

Primary activities for this task are focused on developing and implementing DUV attenuated technology utilizing embedded shifter materials. Development of alternating/phase edge technology is a secondary focus. Similarities will exist in the efforts for 0.35 and 0.25μm technology development, although different materials and tighter specifications will be required for the 0.25μm DUV technology.

7.2.1 Test Pattern Design

A 0.25μm technology test pattern has been designed and submitted for fabrication of attenuated phase shift masks. The patterns represent an array of logic and memory type structures in addition to inspection and repair defect learning vehicles.

7.2.2 0.25μm Technology Mask Deliveries

A total of twenty 0.25μm DUV phase shift masks were delivered. These consisted of 19 carbon DUV attenuated masks and one DUV phase edge mask to fulfill an external request. Image size and image placement specifications were achieved with the DUV carbon masks, but defect levels exceeded targets due to poor incoming substrate quality. Additional details are be included in subsequent sections of this report.

7.2.3 DUV Carbon Embedded Shifter Development

A carbon film developed by the IBM Watson Research Center was selected as the primary material-of-choice for DUV embedded shifter development. Carbon was chosen primarily because of its optical characteristics at the DUV wavelengths, its physical and chemical characteristics for integration into the mask fabrication process, and because no other acceptable films were available through the industry.

Initial films were deposited with a PECVD system. These films exhibited acceptable phase and transmission characteristics, good chemical stability, and acceptable optical stability (less than 0.3% transmission change). Defect and stress levels observed, however, were elevated and unacceptable. Focus then shifted to development of a sputter deposition process to address these issues and to maintain compatibility with industry available deposition equipment.

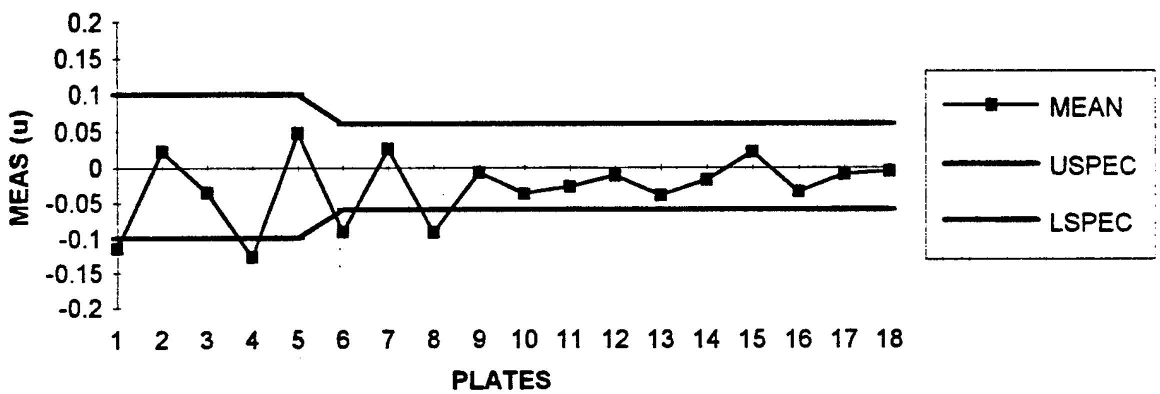
Sputter films were developed and exhibited optical and chemical characteristics similar to the PECVD films, as well as lower stress levels, although the sputter films were less optically stable. Defect levels were difficult to assess due to the environment in which the deposition equipment was located. A strategy was developed to qualify an external vendor for supply of the carbon blanks. IBM Yorktown has worked with an external supplier to transfer their process, and additional work has been focused in three main areas. The vendor focused on centering optical properties of the blanks and on defect reduction, and IBM Yorktown focused on improving the optical stability of the films. Blanks have now been received with phase and transmission centered, although elevated defect levels persist. Sputter targets from three different vendors were evaluated for improvement in defect levels, and additional sputter targets have been ordered for evaluation. A process has been developed by IBM Yorktown that improves optical stability, although a new tool configuration is required to implement this process.

A CORE patterning process was established for the carbon materials using a chrome top layer patterning and wet etch process followed by an O_2 carbon etch process. This process is similar to the I-line molybdenum silicide patterning process, although the RIE etch chemistry for carbon is different than that for molybdenum silicide. The RIE process is extremely directional, and carbon sidewalls of 90 degrees are obtained. An etch bias of zero is also observed. These characteristics lead to improved image size control when referenced to molybdenum silicide.

Image size measurements were qualified on the Siscan system. An SEM correlation was completed with the IBM Standards Laboratory and offsets of $+0.15\mu m$ for lines and $-0.15\mu m$ for spaces have been established. Image placement measurements were qualified on the LMS 2000 system. Figure 13 and Figure 14 show the image size and image placement performance for the $0.25\mu m$ technology masks. Transmission measurement correlations were established with IBM Yorktown and their vendor, and a phase measurement correlation was also initiated.

Early inspection evaluations were performed on the KLA 239 HR tools. As with the embedded chrome, inconsistent results were obtained and focus shifted to the KLA 331 tool. Due to the high transmission of the carbon DUV films at the 488nm KLA 331 wavelength, automatic light calibration cannot be performed, and variable inspection set-up results are observed. A manual calibration has been developed, and samples have been delivered to KLA for development of an automatic routine. Inspections can be performed, although the actual sensitivity of these inspections has not been determined. In addition, the KLA 331 blank inspection routine was also verified.

Mean to Nominal



3 Sigma

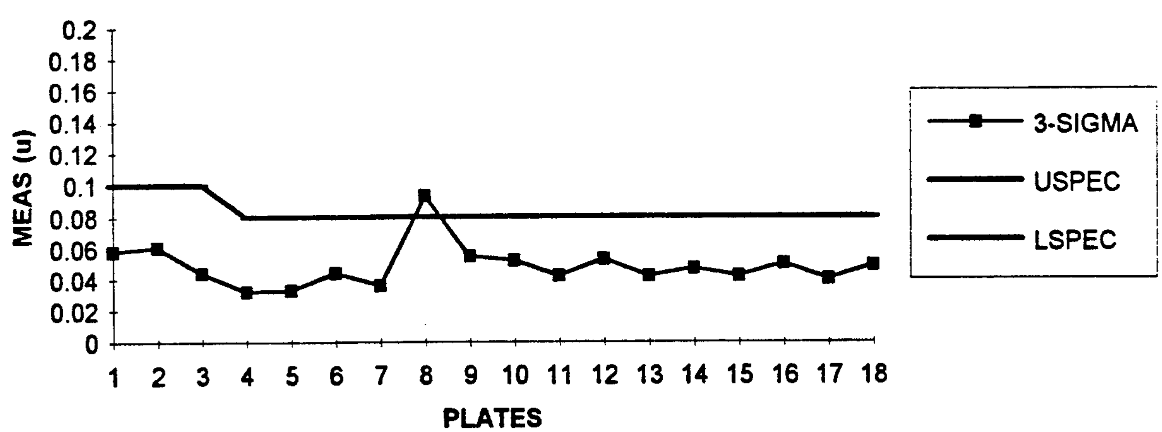


Figure 13. $0.25\mu m$ DUV Embedded Image Size

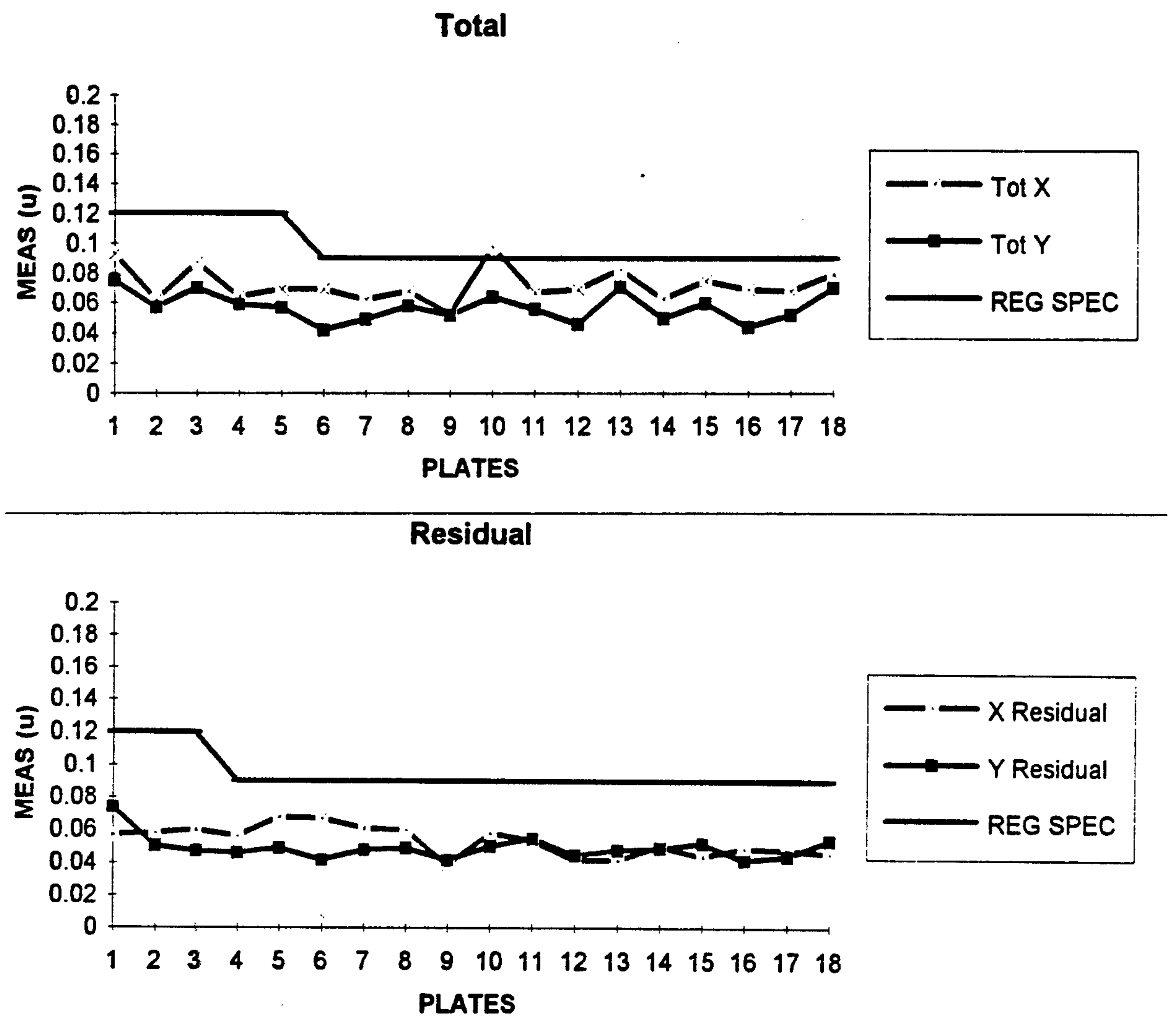


Figure 14. 0.25μm DUV Embedded Registration

As with the I-line attenuated technologies, a laser repair strategy was developed and implemented. Laser power levels were again optimized for the carbon materials, and the clear repair strategy was consistent with the I-line clear repair strategy.

Integration of an opaque frame was also a requirement for the DUV technology. If gratings are used for the DUV masks, required grating images are smaller and more critical than those for I-line masks. Based on this assessment, a non-grating chrome topcoat process compatible with the molybdenum silicide technology was chosen to fabricate these frames

7.3 General Phase Shift Mask Activities

The ALTA tool was qualified

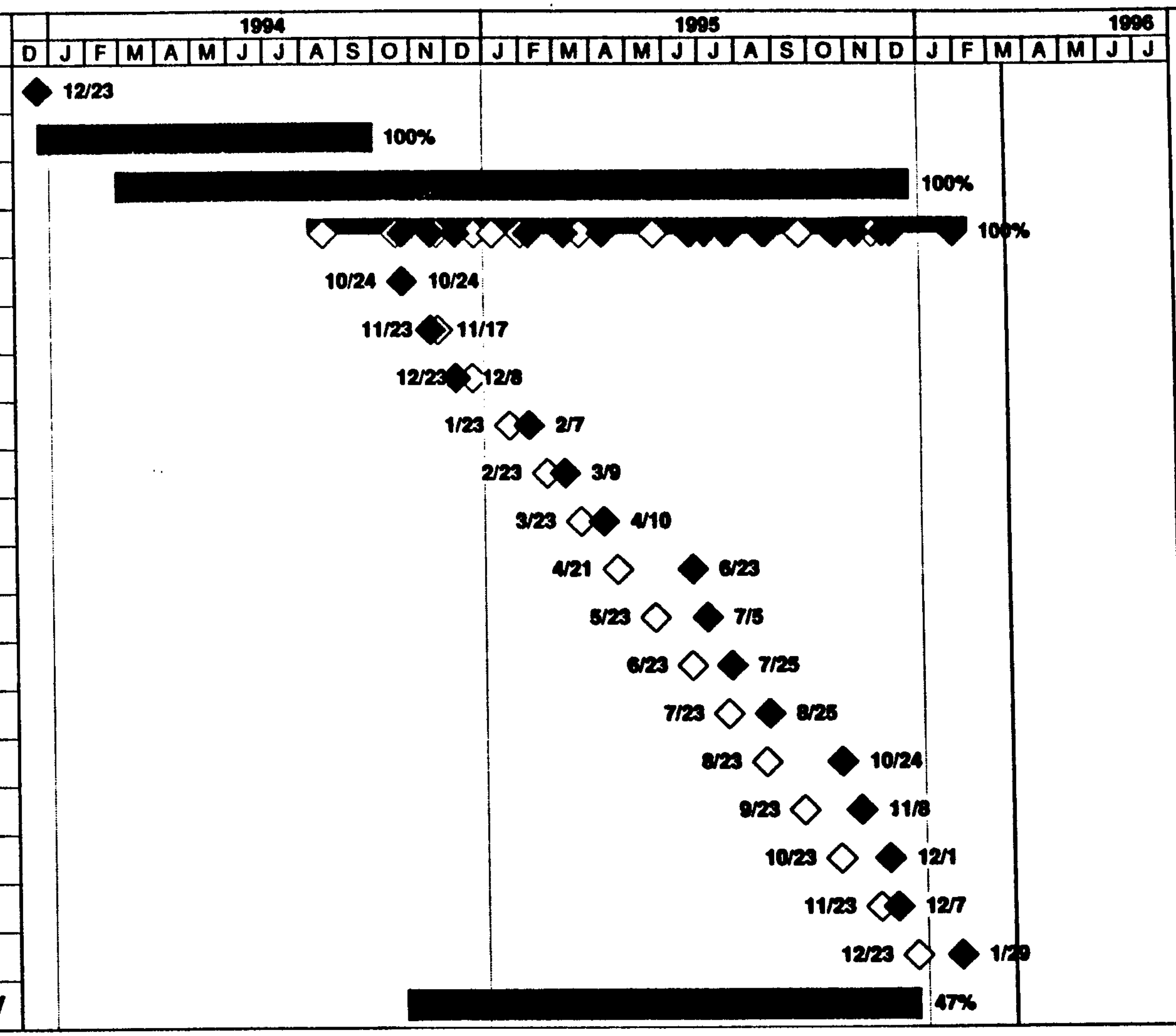
The AIMS tool was installed.

Conversion to industry standard 11% chrome for frames/topcoats was completed.

System Design Reviews were completed for the 0.35μm and 0.25μm technologies.

Appendix A. Program Schedules

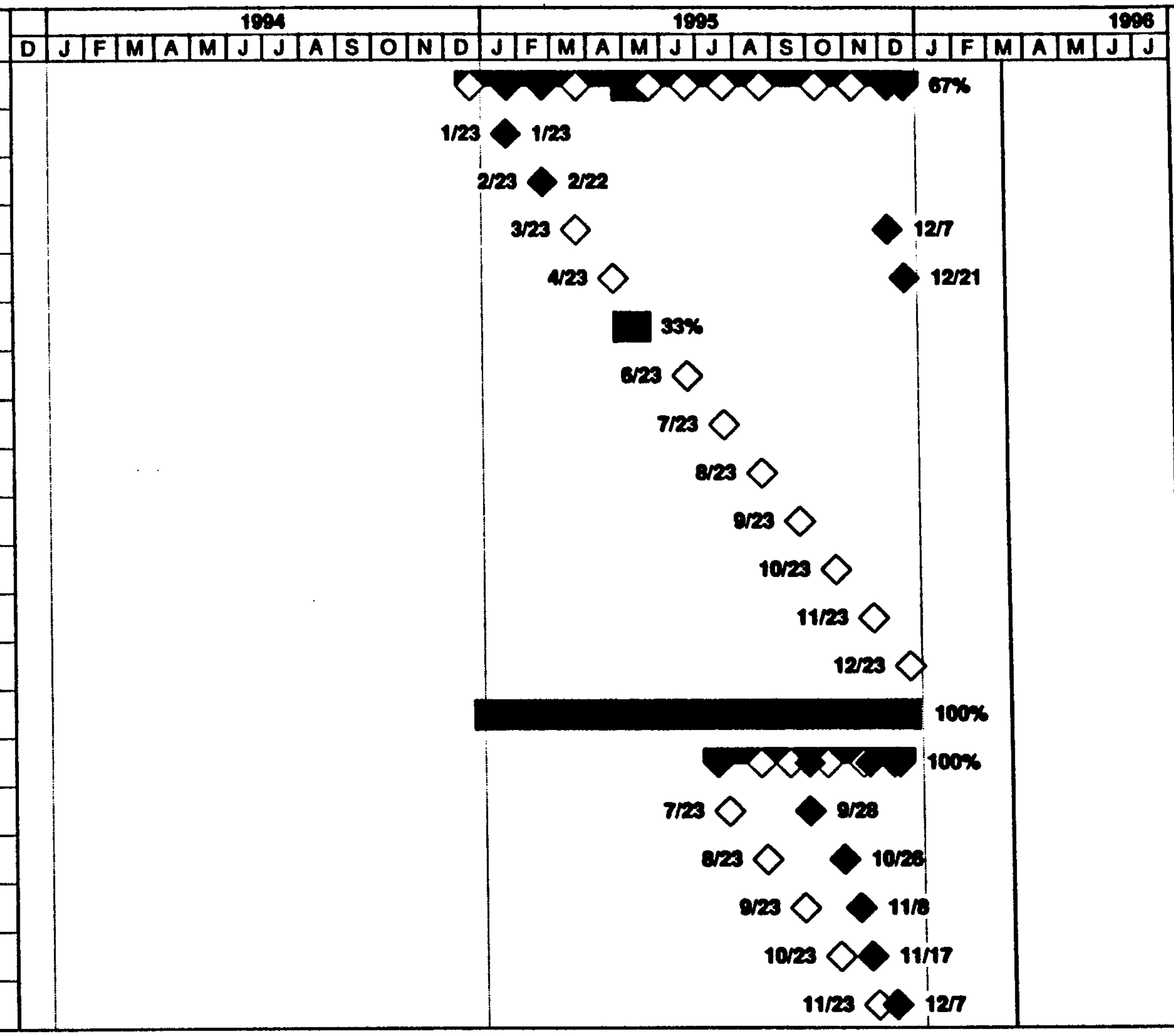
ID	Task Name
1	Contract Award
2	Ramp to 0.25µm Capability
3	**Establish 0.25um Facility**
4	Mask Deliveries -Prototypes
5	Oct Delivery (5)
6	Nov Delivery (5)
7	Dec Delivery (5)
8	Jan. Delivery (5)
9	Feb. Delivery (5) - (Meet Prototype Spec.)
10	Mar Delivery (6)
11	April Delivery (6)
12	May Delivery (7)
13	June Delivery (8)
14	Jul. Delivery (9)
15	Aug. Delivery (9)
16	Sep. Delivery (9)
17	Oct Delivery (9)
18	Nov Delivery (9)
19	Dec Delivery (9)
20	**Establish 0.25µm Defect Learning Capability**



Project: MMD CONTRACT
Date: 3/14/96

Task		Rolled Up Critical Task	
Critical Task		Rolled Up Milestone	◇
Progress		Rolled Up Progress	
Milestone	◇	Completed Milestone	◆
Summary		Rolled Up Completed Milestone	◆
Rolled Up Task			

ID	Task Name
21	**Mask Deliveries - Defect Learning**
22	Jan. Delivery (1)
23	Feb. Delivery (1)
24	Mar Delivery (1)
25	April Delivery (1)
26	May Delivery (3)
27	June Delivery (3)
28	Jul. Delivery (3)
29	Aug. Delivery (3)
30	Sep. Delivery (3)
31	Oct Delivery (3)
32	Nov Delivery (3)
33	Dec Delivery (4)- (Meet Validation Spec.)
34	**Establish 0.18µm Facility**
35	**Mask Deliveries - 0.18um Prototypes**
36	July Delivery (1)
37	August Delivery (2)
38	September Delivery (2)
39	Oct Delivery (2)
40	Nov Delivery (2)



Project: MMD CONTRACT
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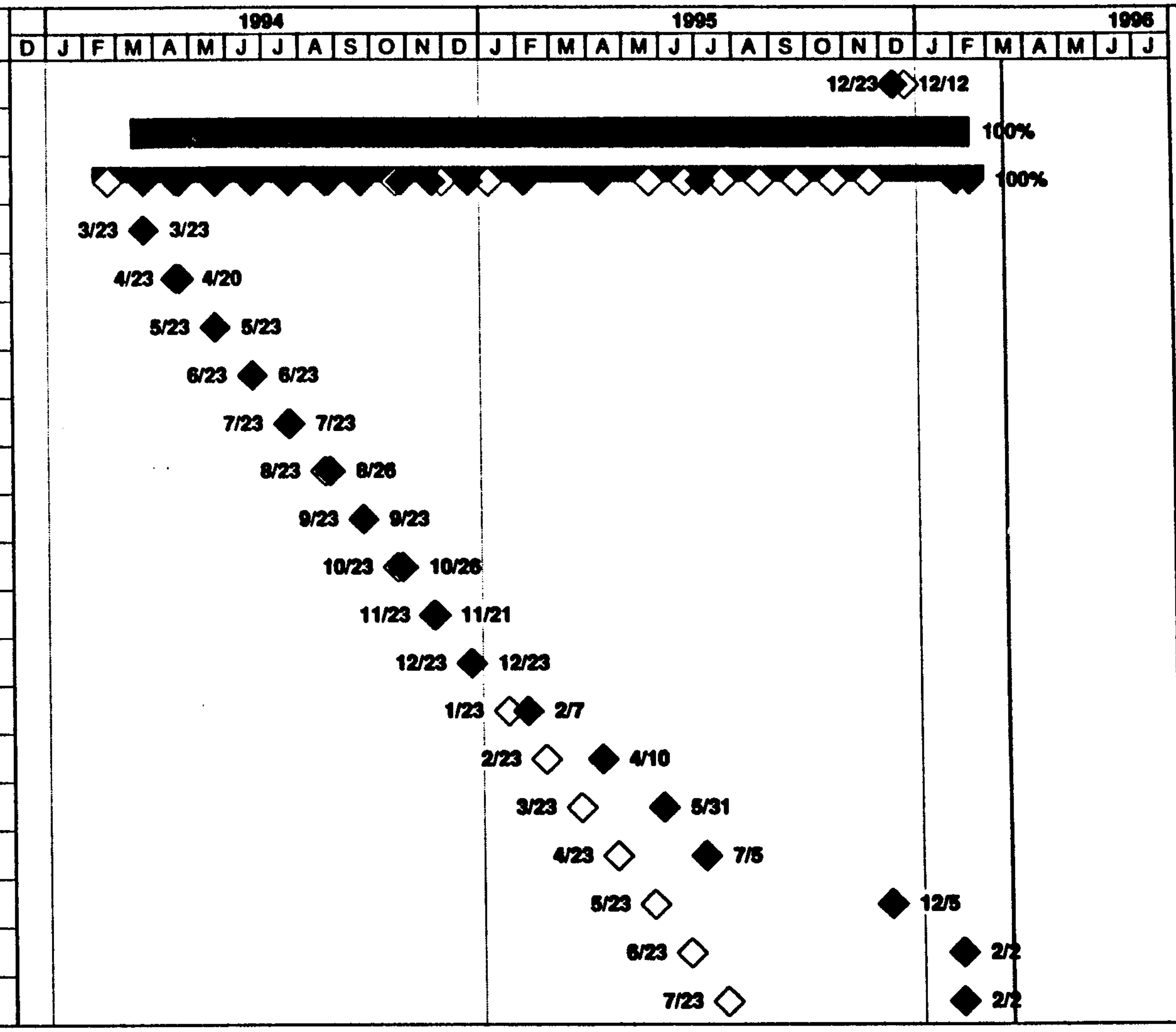
Task	Rolled Up Critical Task
Critical Task	Rolled Up Milestone
Progress	Rolled Up Progress
Milestone	Completed Milestone
Summary	Rolled Up Completed Milestone
Rolled Up Task	

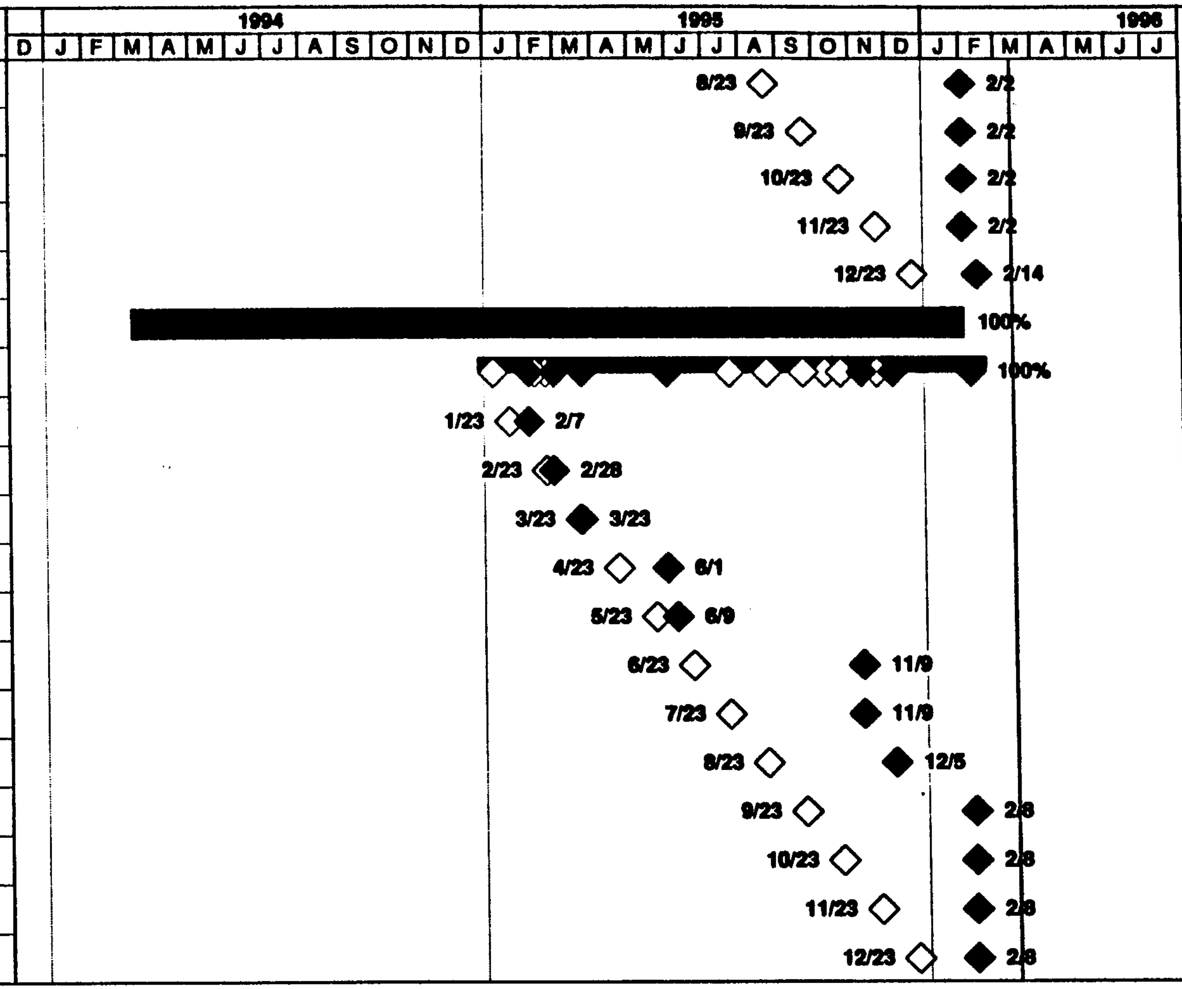
ID	Task Name
41	Dec Delivery (2)- (Meet Prototype Spec.)
42	**Establish 0.35µm PSM Facility**
43	**Mask Deliveries -PSM Prototype**
44	Mar Delivery (1)
45	Apr. Delivery (1)
46	May Delivery (1)
47	June Delivery (1)
48	Jul. Delivery (1)
49	Aug. Delivery (2)
50	Sep. Delivery (2)
51	Oct Delivery (2)
52	Nov Delivery (2)
53	Dec Delivery (2)- (Meet Prototype Spec.)
54	Jan. Delivery (2)
55	Feb. Delivery (2)
56	March Delivery (2)
57	April Delivery (2)
58	May Delivery (2)
59	June Delivery (2)
60	Jul. Delivery (2)



Project: MMD CONTRACT
Date: 3/14/96

Task		Rolled Up Critical Task	
Critical Task		Rolled Up Milestone	◇
Progress		Rolled Up Progress	
Milestone	◇	Completed Milestone	◆
Summary		Rolled Up Completed Milestone	◆
Rolled Up Task			

ID	Task Name
61	Aug. Delivery (2)
62	Sep. Delivery (2)
63	Oct Delivery (2)
64	Nov Delivery (2)
65	Dec Delivery (3)
66	**Establish 0.25µm PSM Facility**
67	**Mask Deliveries - 0.25um PSM Prototype**
68	Jan. Delivery (1)
69	Feb. Delivery (1)
70	Mar Delivery (1)
71	April Delivery (1)
72	May Delivery (1)- (Meet Prototype Spec.)
73	June Delivery (2)
74	Jul. Delivery (2)
75	Aug. Delivery (2)
76	Sep. Delivery (2)
77	Oct Delivery (2)
78	Nov Delivery (2)
79	Dec Delivery (3)



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Legend		Legend	
Task	▬	Rolled Up Critical Task	▨
Critical Task	▨	Rolled Up Milestone	◇
Progress	▬	Rolled Up Progress	▬
Milestone	◇	Completed Milestone	◆
Summary	▬	Rolled Up Completed Milestone	◆
Rolled Up Task	▬		

ID	Task Name	Dates (1994–1996)
80	CDRL's	
81	Quality Control Program	99%
82	Quality Control Program	99%
83	Quality Control Plan - A001	/23, 4/20
84	Quality Control Plan Update - A001	1/23, 1/17
85	Quality Assurance Program Status Report - D00A	1/23, 6/23
86	Quality Assurance Program Status Report - D00A	2/23, 3/7
87	Validation Study - C001	100%
88	Initial C001 Submission	3/22, 4/20
89	C001 Annual Update	1/9
90	SDR 0.25µm C001 Update	10/12, 11/3
91	SDR 0.25µm PSM C001 Update	12/24, 1/9
92	SDR 0.18µm C001 Update	6/14, 5/26
93	Option Update	1/29, 1/25
94	Technology Roadmap - C002	100%
95	C002 Initial Submission	3/22, 4/24
96	SDR 0.25µm C002 Update	9/19, 8/9
97	C002 Annual Update	1/9
98	SDR 0.25µm PSM C002 Update	12/24, 12/23
99	SDR 0.18µm C002 Update	6/14, 5/26

Project: MMD CONTRACT
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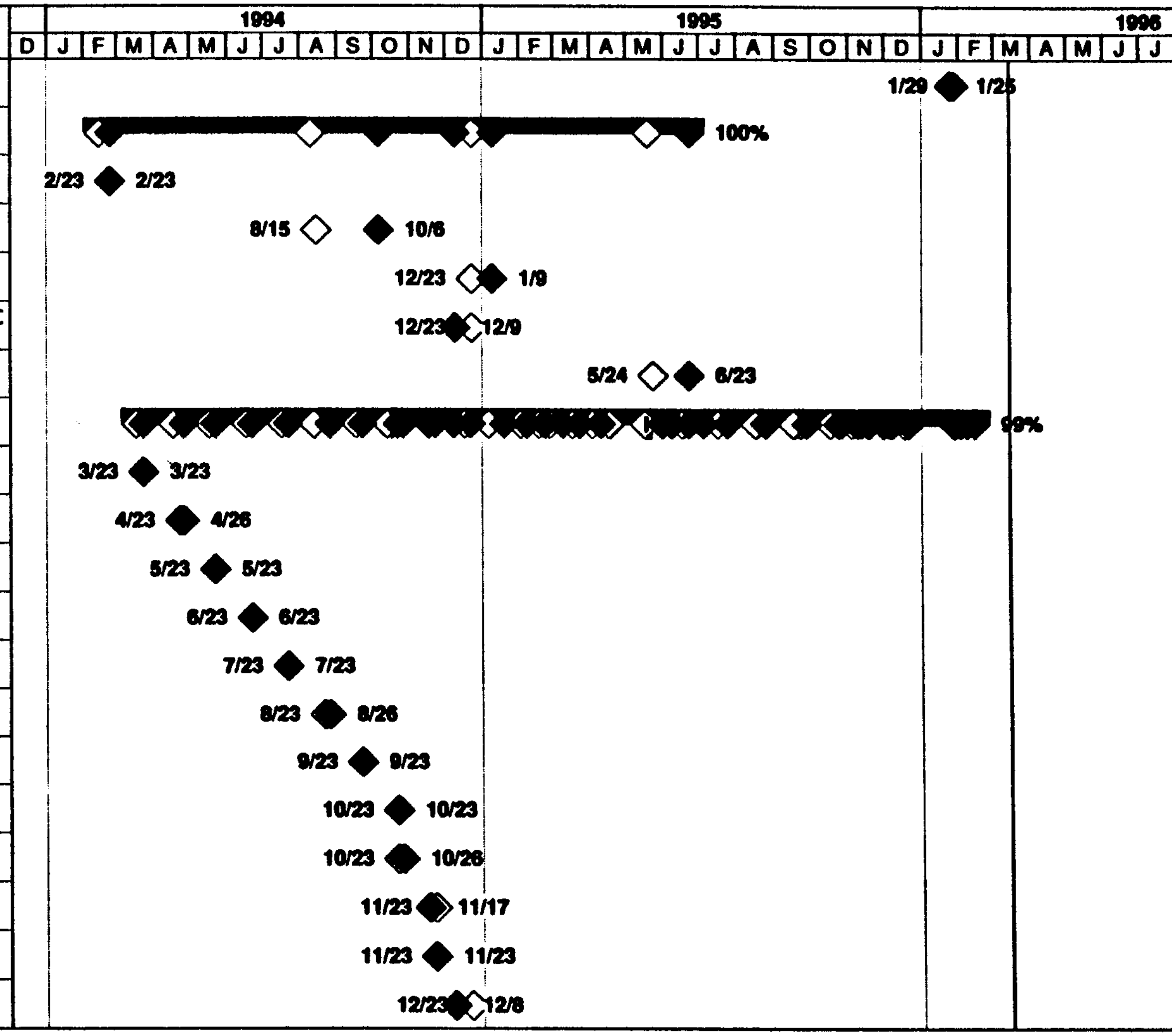
Task	Rolled Up Critical Task
Critical Task	Rolled Up Milestone
Progress	Rolled Up Progress
Milestone	Completed Milestone
Summary	Rolled Up Completed Milestone
Rolled Up Task	

ID	Task Name
100	Option Update
101	**Test Pattern Reports -C003**
102	Test Pattern Report 0.35µm PSM- C003
103	Test Pattern Report 0.25µm - C003
104	Test Pattern Report 0.25µm PSM- C003
105	Test Pattern Report 0.25µm Defect Learning - C0C
106	Test Pattern Report 0.18µm - C003
107	**Metrological Data Package - C004**
108	Mar. - C004
109	April.- C004
110	May.- C004
111	Jun. - C004
112	Jul.- C004
113	Aug.- C004
114	Sep.. - C004
115	Oct. 0.25um Xray - C004
116	Oct. PSM - C004
117	Nov. 0.25um X-ray - C004
118	Nov. PSM- C004
119	Dec. 0.25um Xray - C004



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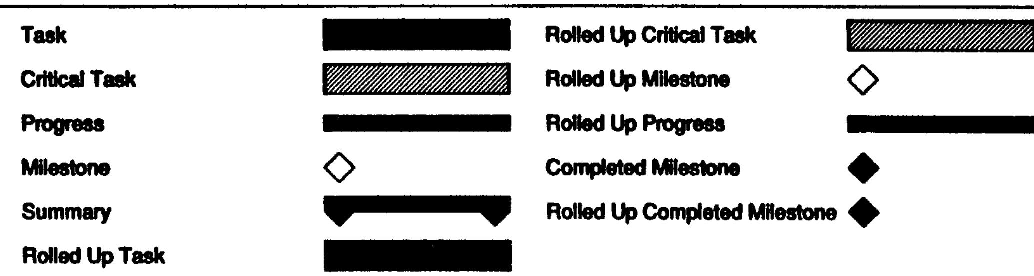

ID	Task Name	1994–1996
120	Dec. PSM - C004	12/23 12/23
121	Jan. 0.25um X-ray- C004	1/23 1/19
122	Jan. 0.25um DL X-ray- C004	1/23 1/19
123	Jan. PSM - C004	1/23 2/7
124	Jan. 0.25um PSM - C004	1/23 2/7
125	Feb.0.25um X-ray- C004	2/23 3/9
126	Feb. 0.25um DL X-ray- C004	2/23 2/22
127	Feb. PSM - C004	2/23 4/10
128	Feb. 0.25um PSM - C004	2/23 3/23
129	Mar. 0.25um X-ray- C004	3/23 4/10
130	Mar. 0.25um DL X-ray- C004	3/23 12/7
131	Mar. PSM - C004	3/23 5/31
132	Mar. 0.25um PSM - C004	3/23 3/23
133	April 0.25um X-ray- C004	4/23 6/23
134	April. 0.25um DL X-ray- C004	4/23 12/21
135	April. PSM - C004	4/23 7/5
136	April. 0.25um PSM - C004	4/23 6/1
137	May. 0.25um X-ray- C004	5/23 7/5
138	May. 0.25um DL X-ray- C004	33%
139	May. PSM - C004	5/23 12/5

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Task
Critical Task
Progress
Milestone
Summary
Rolled Up Task
Rolled Up Critical Task
Rolled Up Milestone
Rolled Up Progress
Completed Milestone
Rolled Up Completed Milestone

ID	Task Name	1994 – 1996
140	May. 0.25um PSM - C004	5/23 ◇ ◆ 6/9
141	Jun. 0.25um X-ray- C004	6/23 ◇ ◆ 7/25
142	Jun. 0.25um DL X-ray- C004	6/23 ◇
143	Jun. PSM - C004	6/23 ◇ ◆ 2/2
144	Jun. 0.25um PSM - C004	6/23 ◇ ◆ 11/9
145	Jul. 0.25um X-ray- C004	7/23 ◇ ◆ 8/25
146	Jul. 0.25um DL X-ray- C004	7/23 ◇
147	Jul 0.18um X-ray - C004	7/23 ◇ ◆ 9/28
148	Jul. PSM - C004	7/23 ◇ ◆ 2/2
149	Jul. 0.25um PSM - C004	7/23 ◇ ◆ 11/9
150	Aug. 0.25um X-ray- C004	8/23 ◇ ◆ 10/24
151	Aug. 0.25um DL X-ray- C004	8/23 ◇
152	Aug. 0.18um X-ray - C004	8/23 ◇ ◆ 10/26
153	Aug. PSM - C004	8/23 ◇ ◆ 2/2
154	Aug. 0.25um PSM - C004	8/23 ◇ ◆ 12/5
155	Sep.. 0.25um X-ray- C004	9/23 ◇ ◆ 11/8
156	Sep. 0.25um DL X-ray- C004	9/23 ◇
157	Sep. 0.18um X-ray - C004	9/23 ◇ ◆ 11/8
158	Sep.. PSM - C004	9/23 ◇ ◆ 2/2
159	Sep..0.25 um PSM - C004	9/23 ◇ ◆ 2/8

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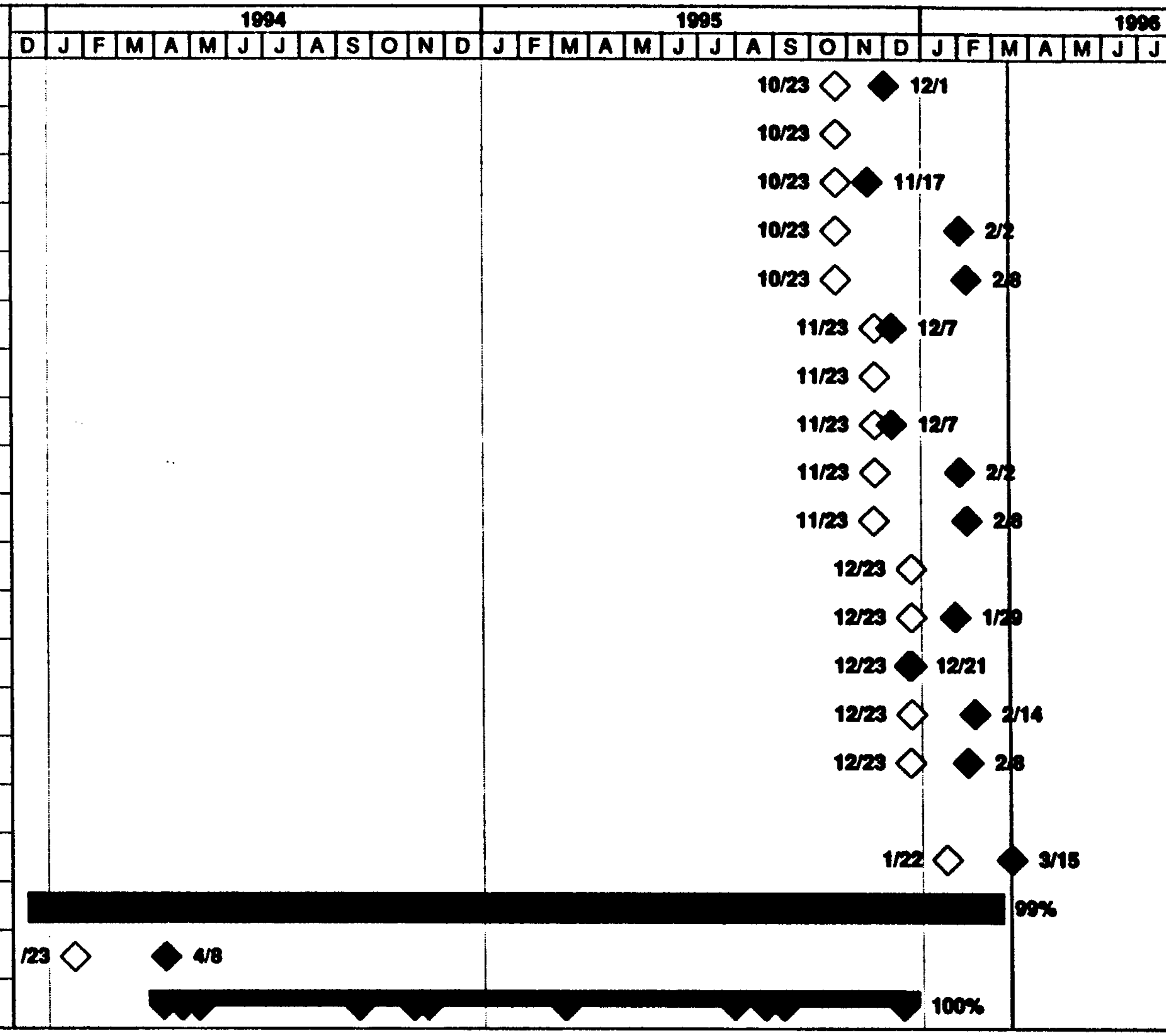
Task		Rolled Up Critical Task	
Critical Task		Rolled Up Milestone	◇
Progress		Rolled Up Progress	
Milestone	◇	Completed Milestone	◆
Summary		Rolled Up Completed Milestone	◆
Rolled Up Task			

ID	Task Name
160	Oct. 0.25um X-ray- C004
161	Oct. 0.25um DL X-ray- C004
162	Oct. 0.18um X-ray - C004
163	Oct. PSM - C004
164	Oct. 0.25um PSM - C004
165	Nov. 0.25um X-ray- C004
166	Nov. 0.25um DL X-ray- C004
167	Nov. 0.18um X-ray - C004
168	Nov. PSM - C004
169	Nov. 0.25um PSM - C004
170	Dec. 0.25um DL X-ray- C004
171	Dec. 0.25um X-ray - C004
172	Dec. 0.18um X-ray - C004
173	Dec. PSM - C004
174	Dec. 0.25um PSM - C004
175	**Validation Report - C005**
176	**R&D Technical Report - C006**
177	**Technology Assessment Report - C007**
178	**Operational Security Plan - C008**
179	**Design Reviews, TIMS - D001**



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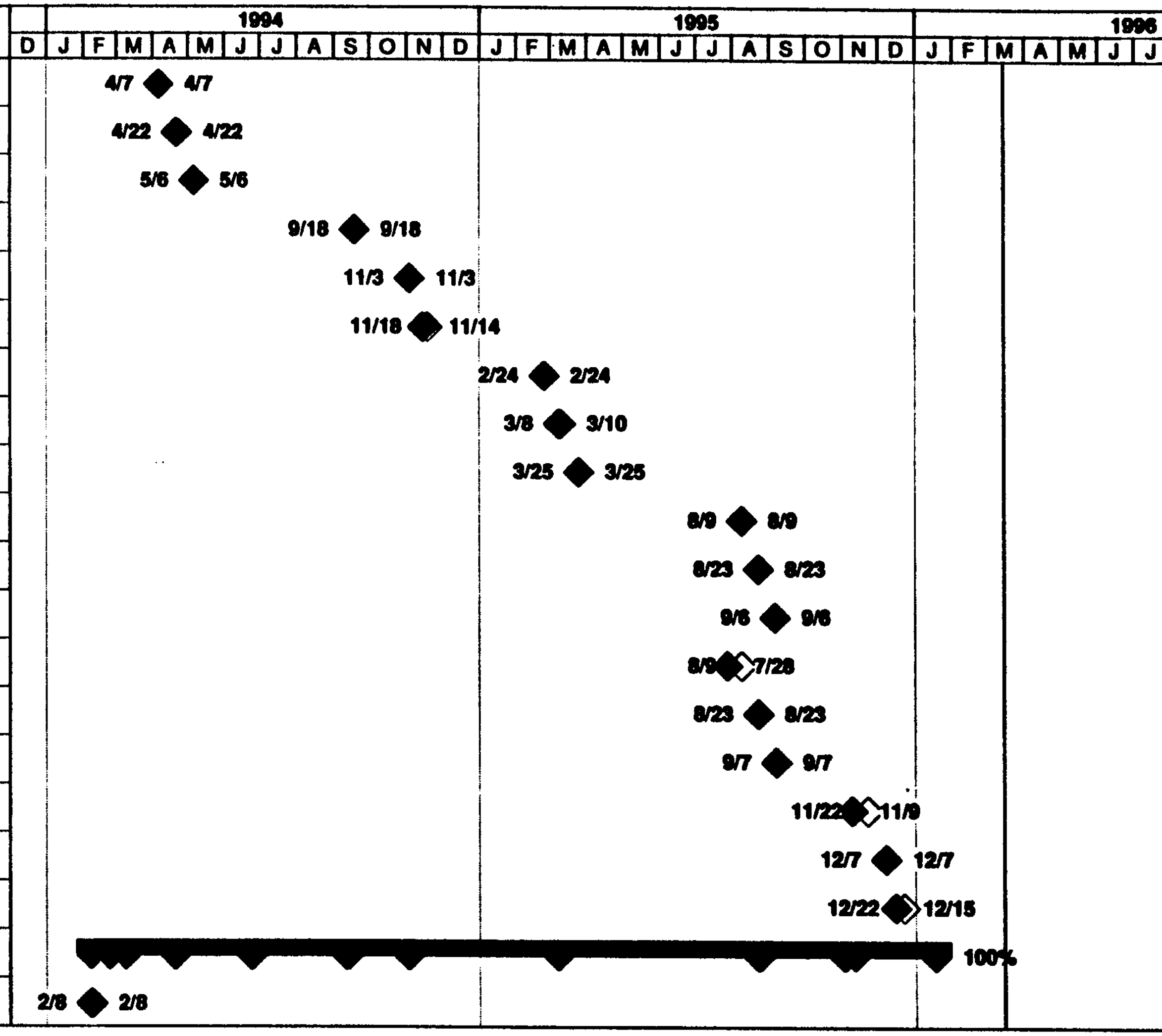
Task		Rolled Up Critical Task	
Critical Task		Rolled Up Milestone	
Progress		Rolled Up Progress	
Milestone		Completed Milestone	
Summary		Rolled Up Completed Milestone	
Rolled Up Task			

ID	Task Name
180	Agenda - D001
181	SDR-0.35µm - PSM
182	Minutes - D002
183	Agenda- D001
184	SDR - 0.25µm
185	Minutes - D002
186	Agenda - D001
187	SDR-0.25µm - PSM
188	Minutes - D002
189	Agenda - D001
190	Executive Review
191	Minutes - D002
192	Agenda - D001
193	SDR - 018µm
194	Minutes - D002
195	Agenda - D001
196	Executive Review
197	Minutes - D002
198	**BI Monthly TIM's**
199	TIM Agenda - D001



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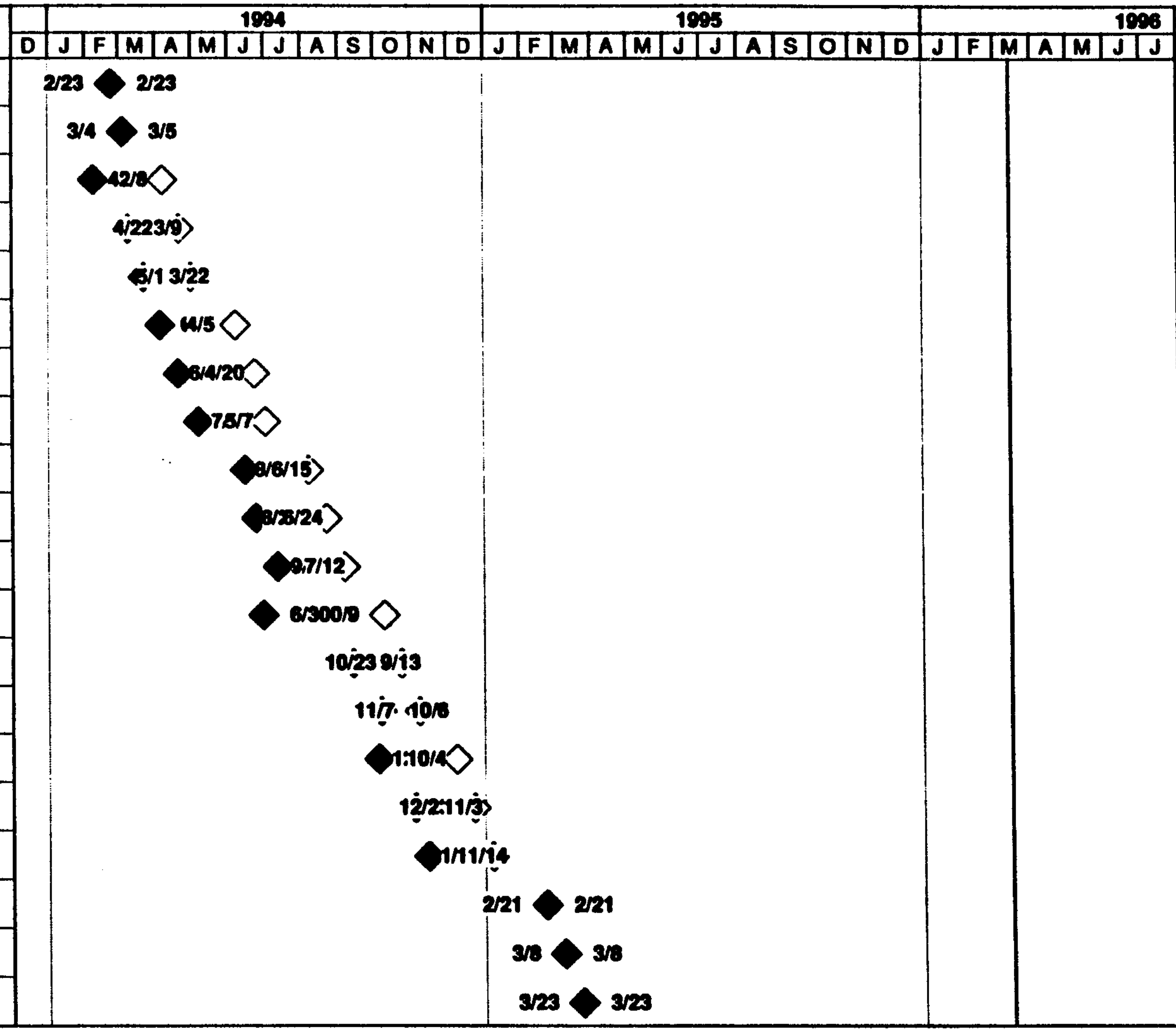
Task	Rolled Up Critical Task
Critical Task	Rolled Up Milestone
Progress	Rolled Up Progress
Milestone	Completed Milestone
Summary	Rolled Up Completed Milestone
Rolled Up Task	

ID	Task Name
200	TIM
201	TIM Minutes - D002
202	TIM Agenda - D001
203	TIM
204	TIM Minutes - D002
205	TIM Agenda - D001
206	TIM
207	TIM Minutes - D002
208	TIM Agenda - D001
209	TIM
210	TIM Minutes - D002
211	TIM Agenda - D001
212	TIM
213	TIM Minutes - D002
214	TIM Agenda - D001
215	TIM
216	TIM Minutes - D002
217	TIM Agenda - D001
218	TIM
219	TIM Minutes - D002



Project: MMD CONTRACT
Date: 3/14/96

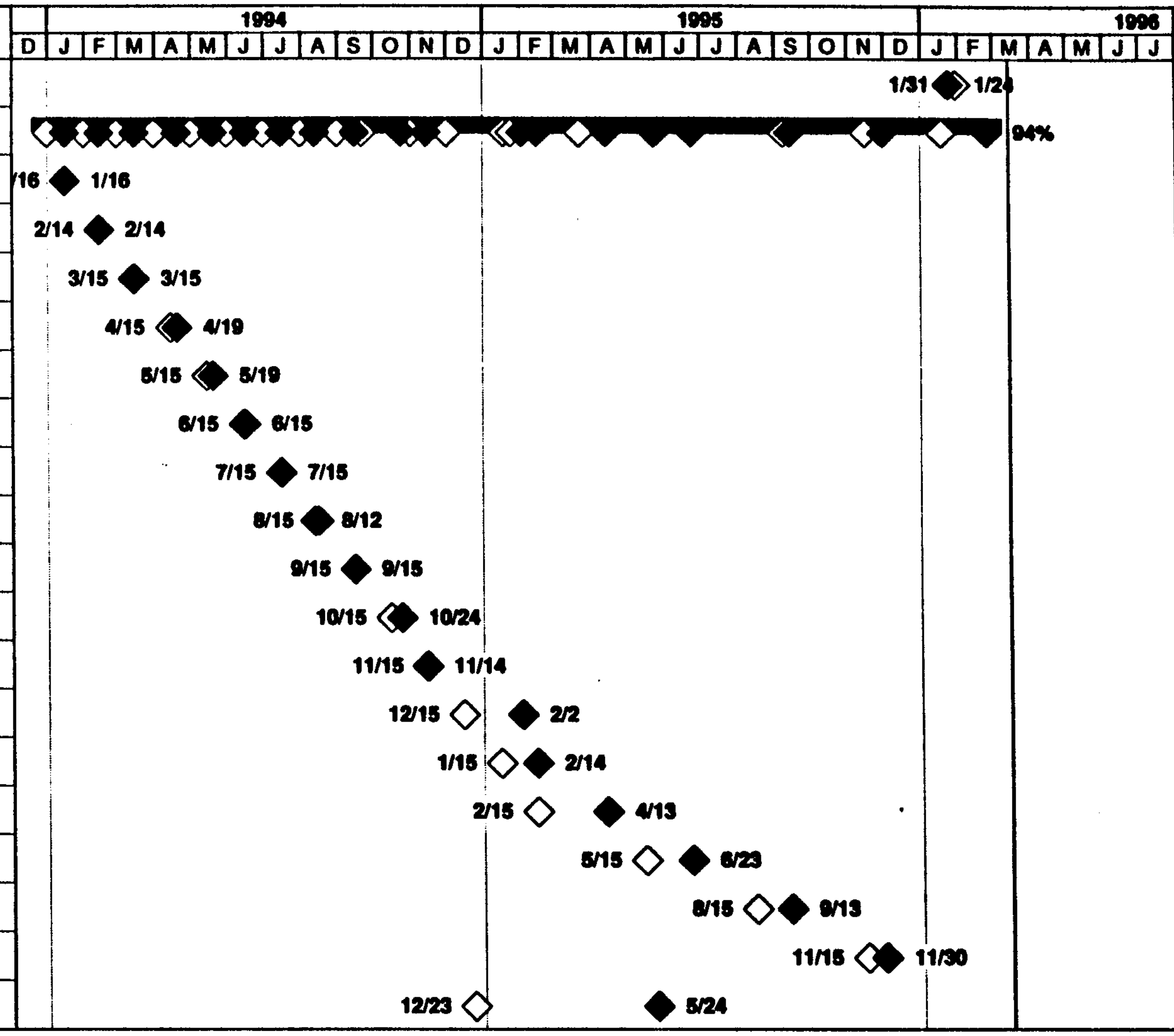
Task	Rolled Up Critical Task
Critical Task	Rolled Up Milestone
Progress	Rolled Up Progress
Milestone	Completed Milestone
Summary	Rolled Up Completed Milestone
Rolled Up Task	

ID	Task Name	1994–1996
220	TIM Agenda - D001	4/8 3/3
221	TIM	4/23 3/7
222	TIM Minutes - D002	5/8 3/23
223	TIM Agenda - D001	8/9 7/28
224	TIM	8/23 8/23
225	TIM Minutes - D002	9/7 9/7
226	TIM Agenda - D001	8/9 7/28
227	TIM	8/24 8/24
228	TIM Minutes - D002	9/8 9/7
229	TIM Agenda - D001	10/18 10/16
230	TIM	11/3 11/3
231	TIM Minutes - D002	11/17 11/28
232	TIM Agenda - D001	10/26 10/18
233	TIM	11/11 11/11
234	TIM Minutes - D002	11/25 1/17
235	**Design Review, Tim Agenda**	100%
236	**Design Review, TIM Minutes - D002**	100%
237	**Income Statement, Balance Sheet - D003**	100%
238	D003 Initial Draft	12/23 12/23
239	D003 Statement & Balance 1994	1/31 2/6

Project: MMD CONTRACT
Date: 3/14/96

Task	Rolled Up Critical Task
Critical Task	Rolled Up Milestone
Progress	Rolled Up Progress
Milestone	Completed Milestone
Summary	Rolled Up Completed Milestone
Rolled Up Task	

ID	Task Name
240	D003 Statement & Balance 1995
241	Monthly/Annual Reports -D004
242	Dec. D004
243	Jan.D004
244	Feb.D004
245	Mar. D004
246	April.D004
247	May. D004
248	Jun. D004
249	Jul. D004
250	Aug. D004
251	Sep. D004
252	Oct. D004
253	Nov. D004
254	Dec. D004
255	Jan. D004
256	April. D004
257	Jul. D004
258	Oct. D004
259	Annual Report - D004



Project: MMD CONTRACT
Date: 3/14/96

Task		Rolled Up Critical Task	
Critical Task		Rolled Up Milestone	
Progress		Rolled Up Progress	
Milestone		Completed Milestone	
Summary		Rolled Up Completed Milestone	
Rolled Up Task			

ID	Task Name	1994–1996
260	Contract Summary - D005	2/25 3/19
261	Monthly CPR - D006	100%
262	Jan. - D006	2/25 2/24
263	Feb. - D006	3/25 3/27
264	Mar - D006	4/25 4/25
265	Apr. - D006	5/25 5/25
266	May - D006	6/25 6/24
267	Jun - D006	7/25 7/25
268	Jul. - D006	8/25 8/25
269	Aug. - D006	9/25 9/25
270	Sept. - D006	10/25 10/25
271	Oct - D006	11/25 11/18
272	Nov - D006	12/25 12/25
273	Dec - D006	1/25 1/25
274	Jan. - D006	2/25 2/23
275	Feb. - D006	3/25 3/24
276	Mar - D006	4/25 4/21
277	Apr. - D006	5/25 5/25
278	May - D006	6/25 6/25
279	Jun - D006	7/25 7/25

Timeline: 1994: D J F M A M J J A S O N D; 1995: J F M A M J J A S O N D; 1996: J F M A M J J

Project: MMD CONTRACT
Date: 3/14/96

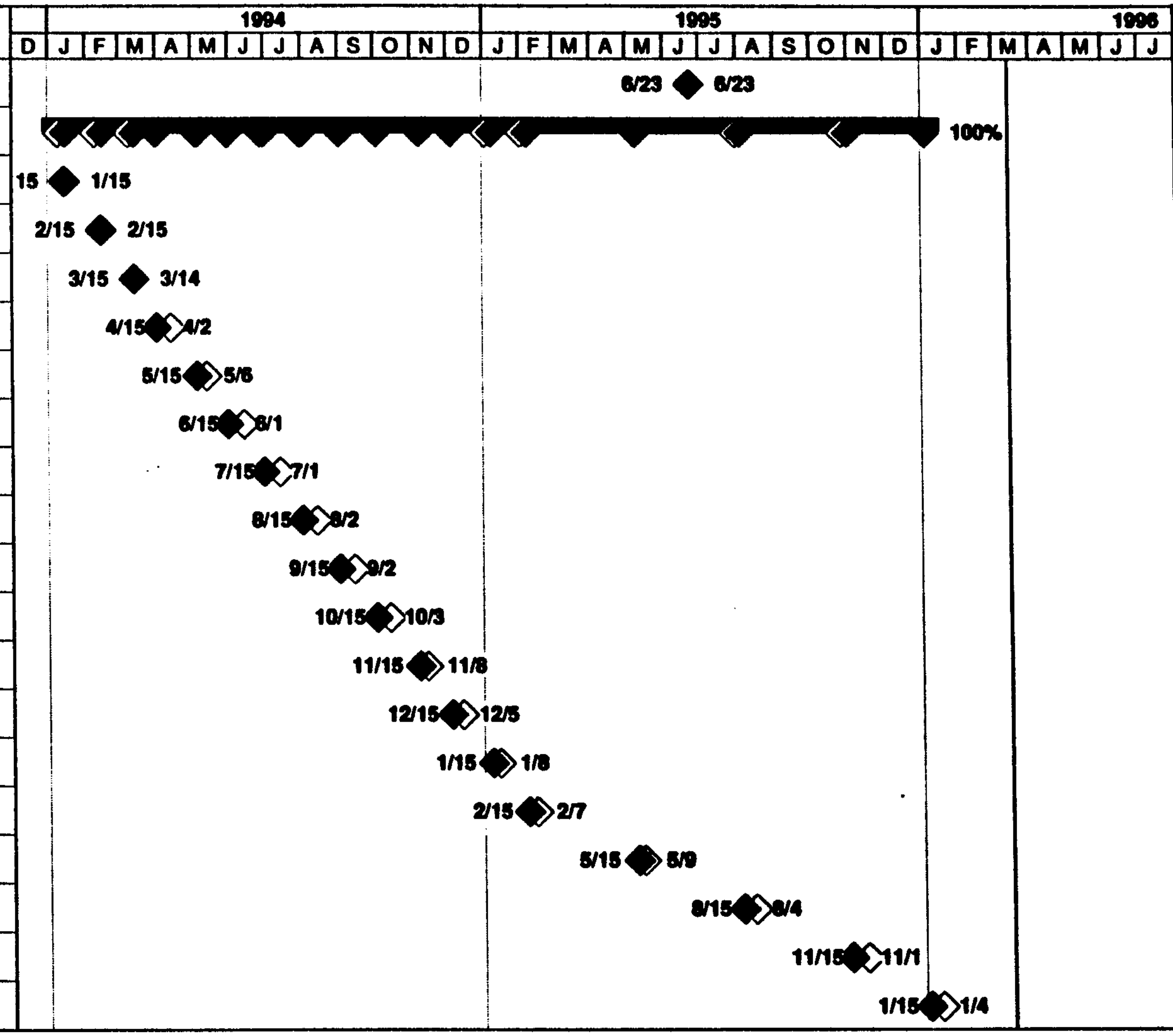
Task	Rolled Up Critical Task
Critical Task	Rolled Up Milestone
Progress	Rolled Up Progress
Milestone	Completed Milestone
Summary	Rolled Up Completed Milestone
Rolled Up Task	

ID	Task Name	Schedule (1994–1996)
280	Jul. - D006	8/25 ◆ 8/25
281	Aug. - D006	9/25 ◆ 9/23
282	Sept. - D006	10/25 ◆ 10/20
283	Oct - D006	11/25 ◆ 11/20
284	Nov D006	12/25 ◆ 12/21
285	Dec - D006	1/25 ◆ 1/25
286	CFSR - D007	100%
287	Initial Submission- D007	/25 ◆ 1/25
288	1Q94 - D007	4/25 ◆ 4/25
289	2Q94 - D007	7/25 ◆ 7/25
290	3Q94 D007	10/25 ◆ 10/25
291	4Q94 D007	1/25 ◆ 1/25
292	1Q95 D007	4/25 ◆ 4/25
293	2Q95 D007	7/25 ◆ 7/25
294	3Q95 D007	10/25 ◆ 10/20
295	4Q95 D007	1/25 ◆ 1/25
296	Contract Work Breakdown - D009	100%
297	Contract Work Breakdown - D009	/24 ◆ 1/24
298	Contract Work Breakdown -Update - D009	5/2 ◆ 5/2
299	Contract Work Breakdown -Update - D009	3/31 ◆ 3/31

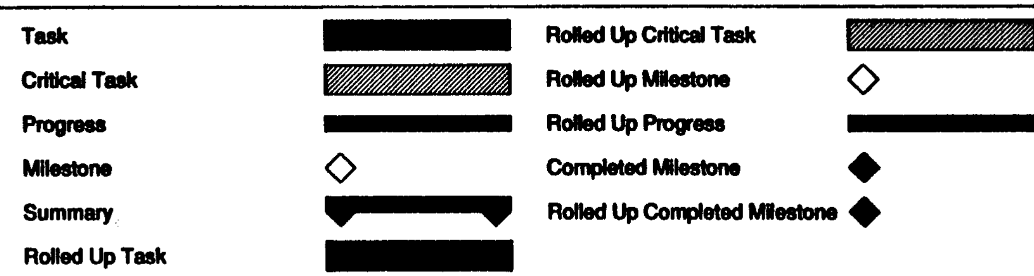
Project: MMD CONTRACT
Date: 3/14/96

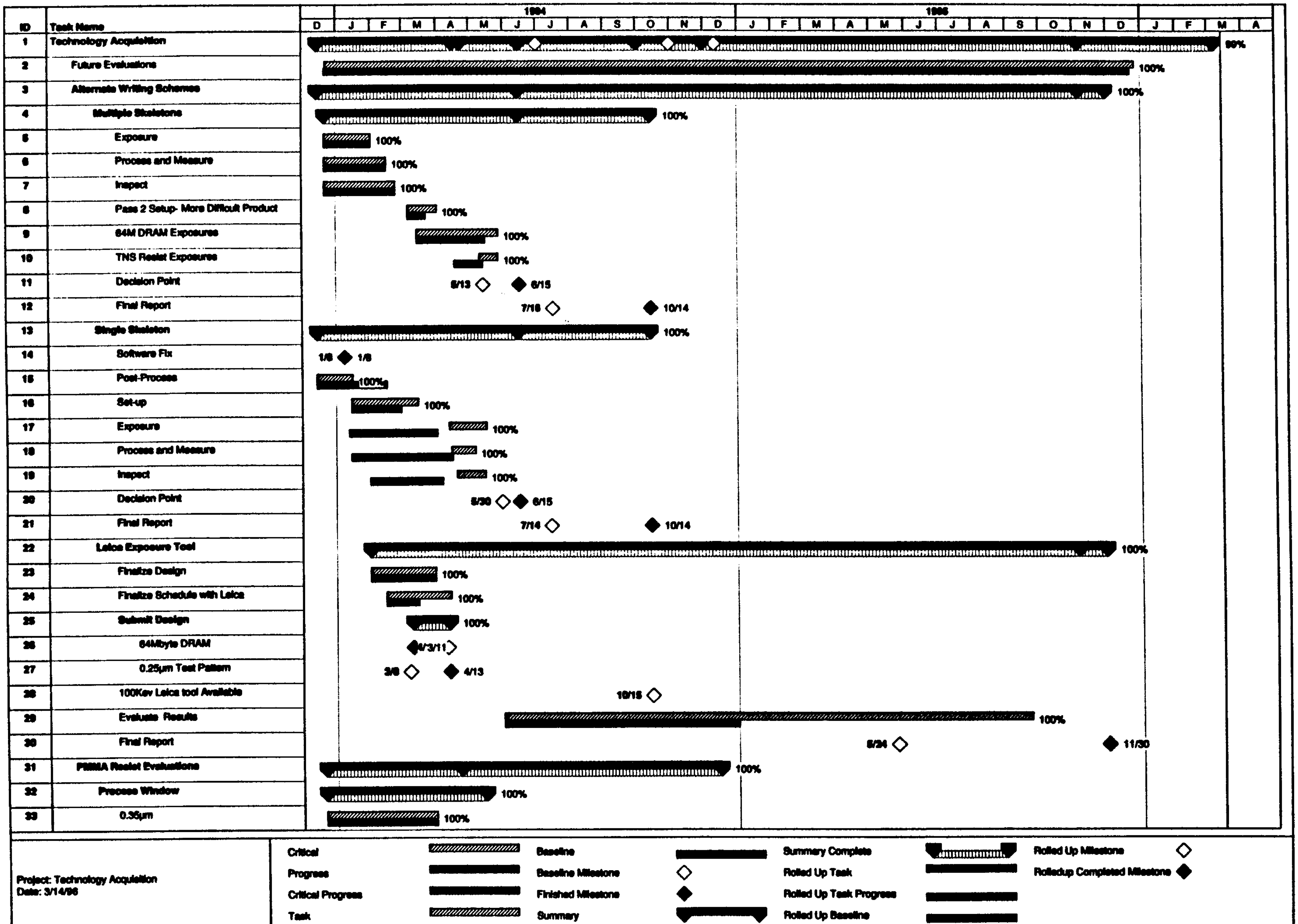
Task		Rolled Up Critical Task	
Critical Task		Rolled Up Milestone	◇
Progress		Rolled Up Progress	
Milestone	◇	Completed Milestone	◆
Summary		Rolled Up Completed Milestone	◆
Rolled Up Task			

ID	Task Name
300	Contract Work Breakdown - Update
301	Data Accession List - D008
302	Dec. D008
303	Jan.D008
304	Feb.D008
305	Mar. D008
306	April. D008
307	May. D008
308	Jun. D008
309	Jul.D008
310	Aug.D008
311	Sep. D008
312	Oct. D008
313	Nov. D008
314	Dec.D008
315	Jan. D008
316	April. D008
317	Jul. D008
318	Oct. D008
319	Dec. D008



Project: MMD CONTRACT
Date: 3/14/96



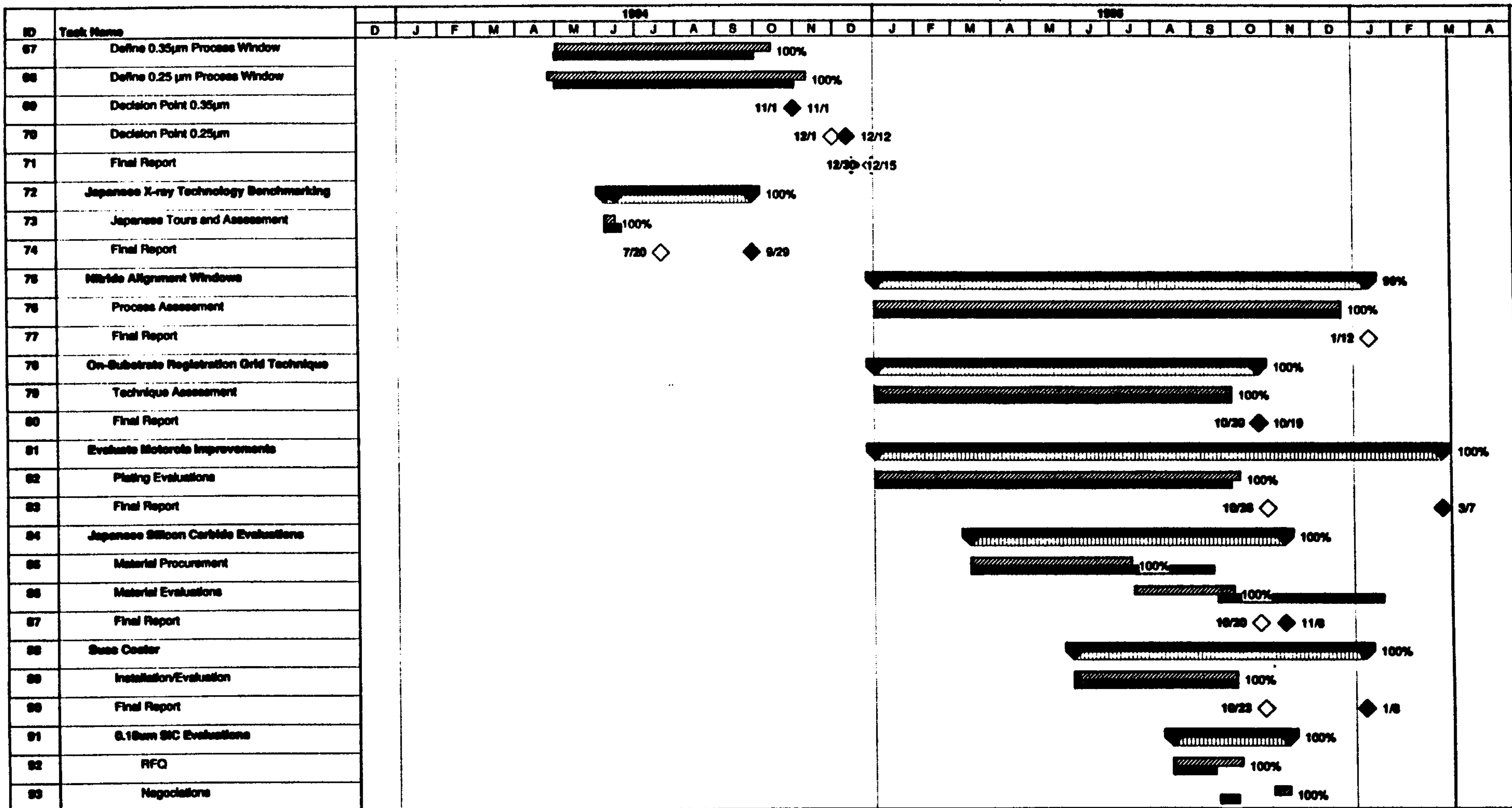

ID
Task Name
1994
1995
D J F M A M J J A S O N D J F M A M J J A S O N D J F M A
1 Technology Acquisition 99%
2 Future Evaluations 100%
3 Alternate Writing Schemes 100%
4 Multiple Skeletons 100%
5 Exposure 100%
6 Process and Measure 100%
7 Inspect 100%
8 Pass 2 Setup- More Difficult Product 100%
9 64M DRAM Exposures 100%
10 TNS Resist Exposures 100%
11 Decision Point 5/13 6/15
12 Final Report 7/18 10/14
13 Single Skeleton 100%
14 Software Fix 1/6 1/6
15 Post-Process 100%
16 Set-up 100%
17 Exposure 100%
18 Process and Measure 100%
19 Inspect 100%
20 Decision Point 5/30 6/15
21 Final Report 7/14 10/14
22 Leica Exposure Tool 100%
23 Finalize Design 100%
24 Finalize Schedule with Leica 100%
25 Submit Design 100%
26 64Mbyte DRAM 4/3/11
27 0.25µm Test Pattern 3/8 4/13
28 100Kev Leica tool Available 10/16
29 Evaluate Results 100%
30 Final Report 5/24 11/30
31 PMMA Resist Evaluations 100%
32 Process Window 100%
33 0.35µm 100%
Project: Technology Acquisition
Date: 3/14/96
Critical
Progress
Critical Progress
Task
Baseline
Baseline Milestone
Finished Milestone
Summary
Summary Complete
Rolled Up Task
Rolled Up Task Progress
Rolled Up Baseline
Rolled Up Milestone
Rollup Completed Milestone

ID	Task Name	Chart labels
34	0.25µm	100%
35	Decision Point - 35µm	3/31 ◆ 3/31
36	Decision Point - 0.25µm	4/18 4/21
37	Final Report	5/22 ◇; ◆ 12/15
38	Silicon Carbide Substrate Evaluation	100%
39	Receive Samples	100%
40	Test Parameters	100%
41	Optical Qualities	100%
42	Physical Qualities	100%
43	Material Qualities	100%
44	Lifetime Test	100%
45	Vendor Selection	◆ 4/15 6/15 ◇
46	Final Report	5/15 ◇; ◆ 7/19
47	MIT Tungsten	100%
48	Design OPD/IPD Pattern	100%
49	Evaluate Stress Uniformity	100%
50	Follow-ups	100%
51	Final Report	10/31 10/14
52	Additive Tungsten Evaluations	100%
53	Process Development	100%
54	On Wafers	100%
55	Negative Resist Evaluations	100%
56	Choose Candidates	100%
57	Vendor Supplied Evaluation	100%
58	Review Results with Vendor	100%
59	Receive Recommendations	100%
60	Order New Material	100%
61	Evaluate New Material (50KEV)	100%
62	Safe Solvent PMMA	100%
63	Obtain Safety Clearance	100%
64	Acquire Samples	100%
65	Define Process	100%
66	Process Checkpoint	7/1 ◆ 7/1

Timescale: 1994 — D J F M A M J J A S O N D; 1995 — J F M A M J J A S O N D; J F M A

Project: Technology Acquisition
Date: 3/14/96

Critical		Baseline		Summary Complete		Rolled Up Milestone	◇
Progress		Baseline Milestone	◇	Rolled Up Task		Rollup Completed Milestone	◆
Critical Progress		Finished Milestone	◆	Rolled Up Task Progress			
Task		Summary		Rolled Up Baseline			



Critical	Baseline	Summary Complete	Rolled Up Milestone
Progress	Baseline Milestone	Rolled Up Task	Rollecup Completed Milestone
Critical Progress	Finished Milestone	Rolled Up Task Progress	
Task	Summary	Rolled Up Baseline	

Project: Technology Acquisition
Date: 3/14/96